Nuclear Power

THE JOURNAL OF BRITISH NUCLEAR ENGINEERING

We work for the New Age

THE AGREEMENT between Mitchell Engineering Ltd of London and AMF Atomics Inc of New York, will undoubtedly have far-reaching effect in applying atomic power for the benefit of mankind.

Created for the joint design and construction of nuclear power plant in the Commonwealth and other countries, it is private industry's first international agreement in this field — and the logical outcome of Mitchell's exceptionally wide experience over the past 35 years in all branches of engineering and electrical supply.

MITCHELL COMPANIES—active in the atomic sphere since 1950—are at present engaged on three important contracts for the United Kingdom Atomic Energy Authority.

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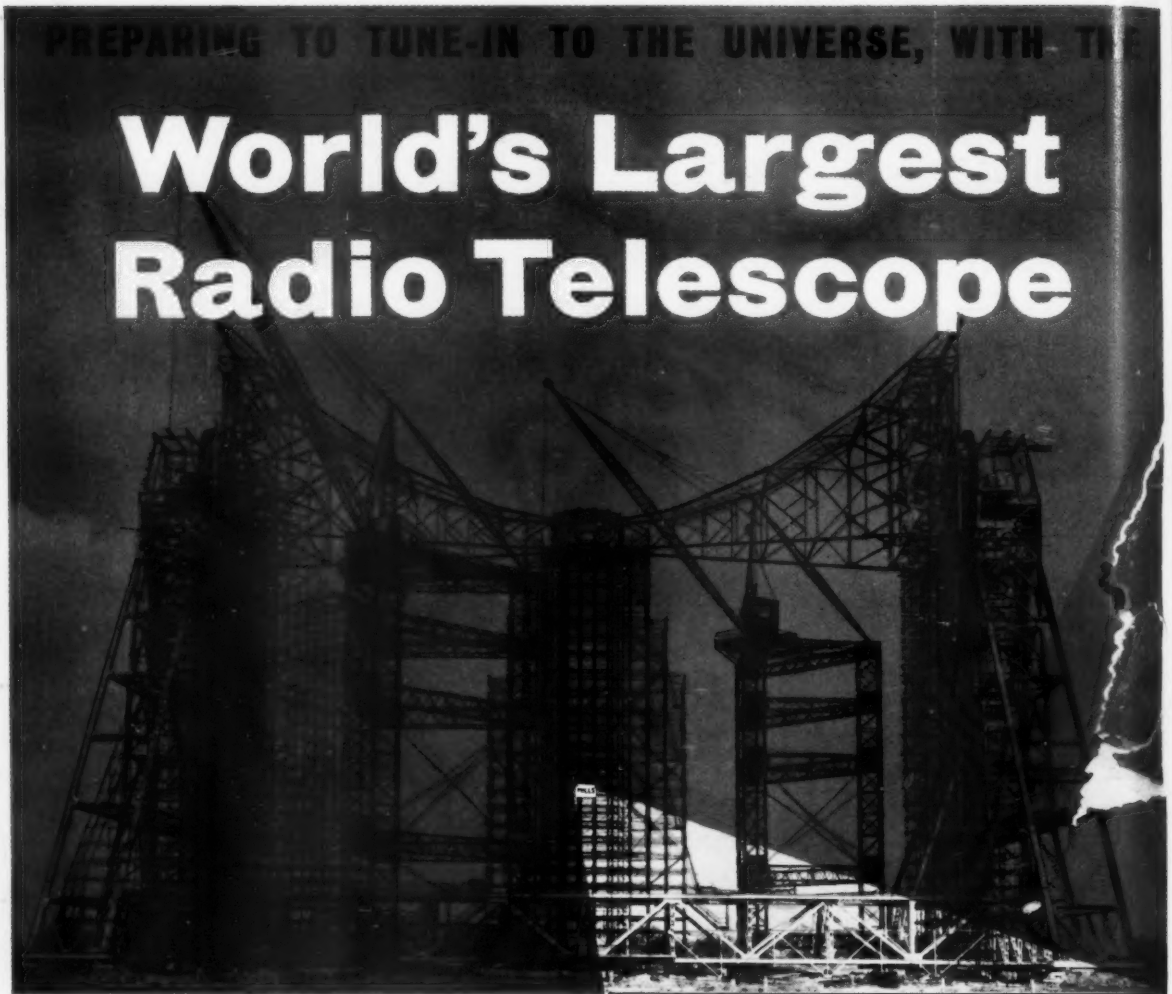
April 1957 Volume 2 Number 12 3s 6d



ALTAZIMUTH PARABOLOID RADIO REFLECTOR AT THE JODRELL BANK SITE, BUILT FOR MANCHESTER UNIVERSITY AND THE DEPARTMENT OF SCIENTIFIC & INDUSTRIAL RESEARCH. CONSULTING ENGINEERS: HUSBAND & CO., SHEFFIELD. STEELWORK CONTRACTORS: UNITED STEEL STRUCTURAL CO. LTD.

Scaffolding by

MILLS

RADIO SIGNALS have been received from points in outer space where nothing can be seen even with the aid of the most powerful telescopes.

It has been established that these signals are of natural origin, from stars unknown to classical astronomy because the radiations from them are in sections of the spectrum which do not constitute light visible to the human eye.

The study of the number and nature of these stars, and the part they play in the universe, has created the science of radio astronomy, which this great new instrument, the first of its kind in the world, will do much to further.

SOME ENGINEERING DETAILS:

Height to the top of the Towers: 185 ft. Height to the Trunnion Bearings: 166 ft. 8 ins. Internal diameter of the Bowl: 250 ft. Depth of the Bowl: 73 ft. 4 ins. Weight of the Bowl, with cross girder: 900 tons—**carried on MILLS Scaffolding during construction.**

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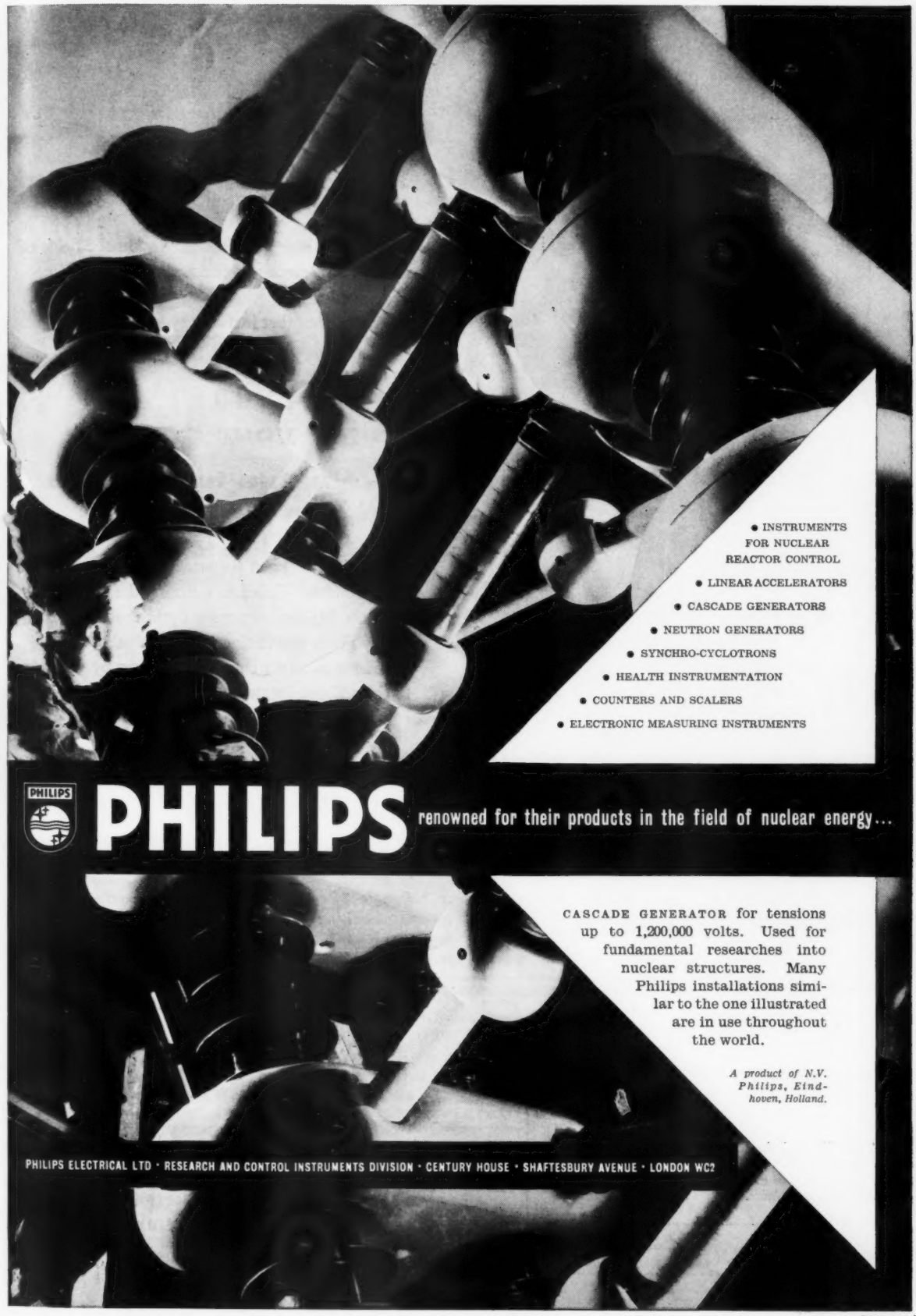
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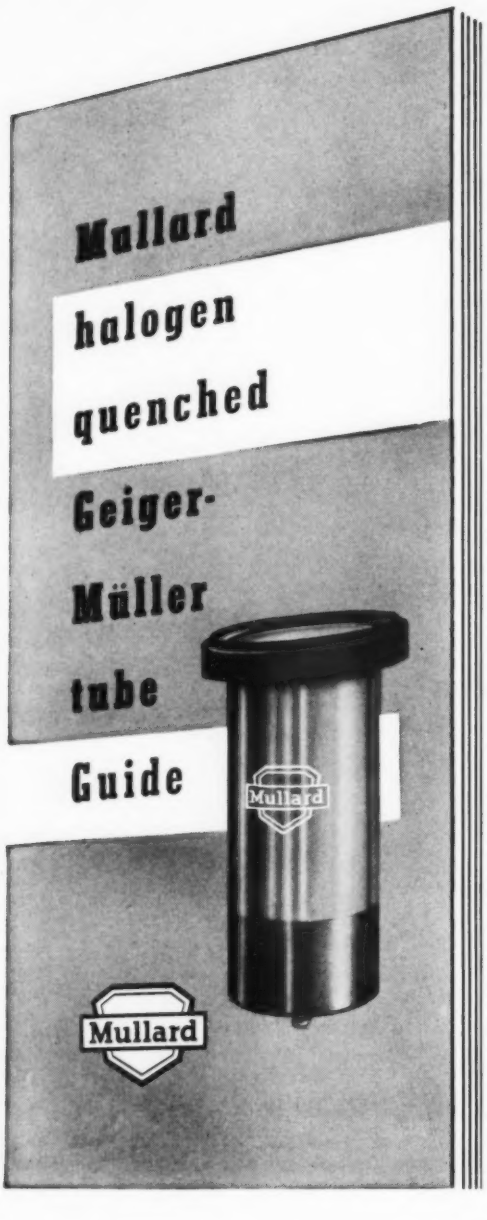

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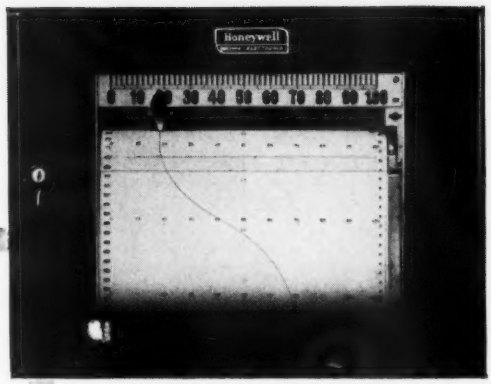

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REFERENCE DATA
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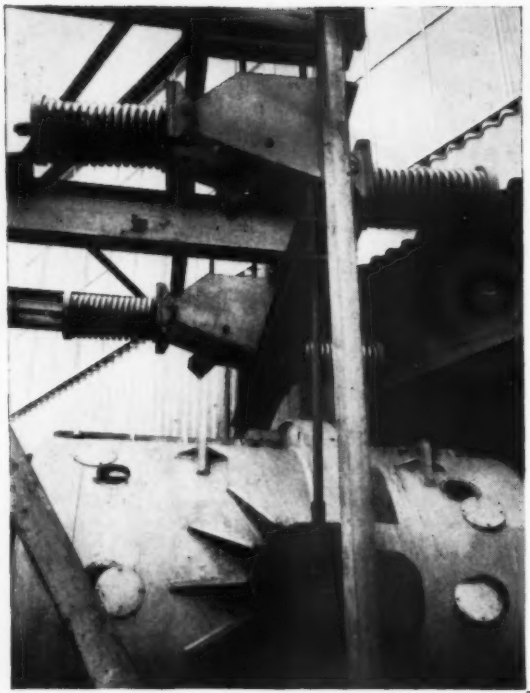

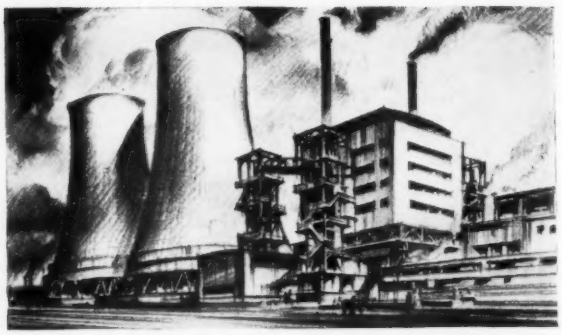

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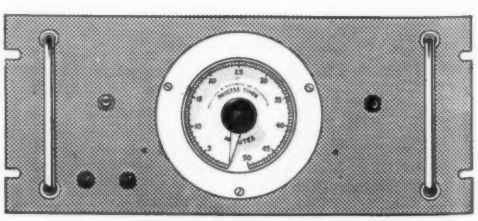

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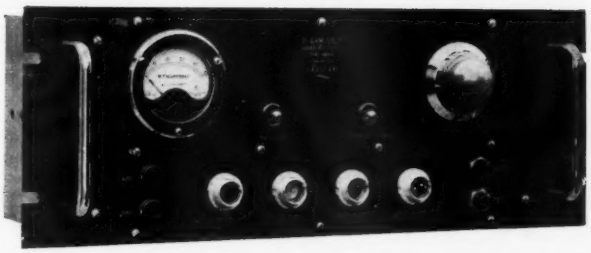

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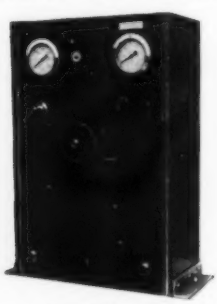

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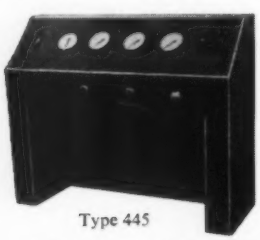

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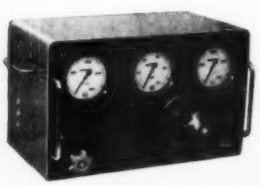

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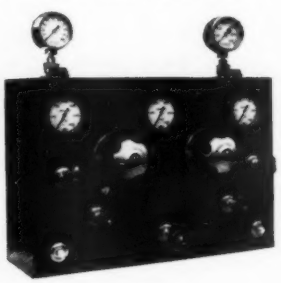

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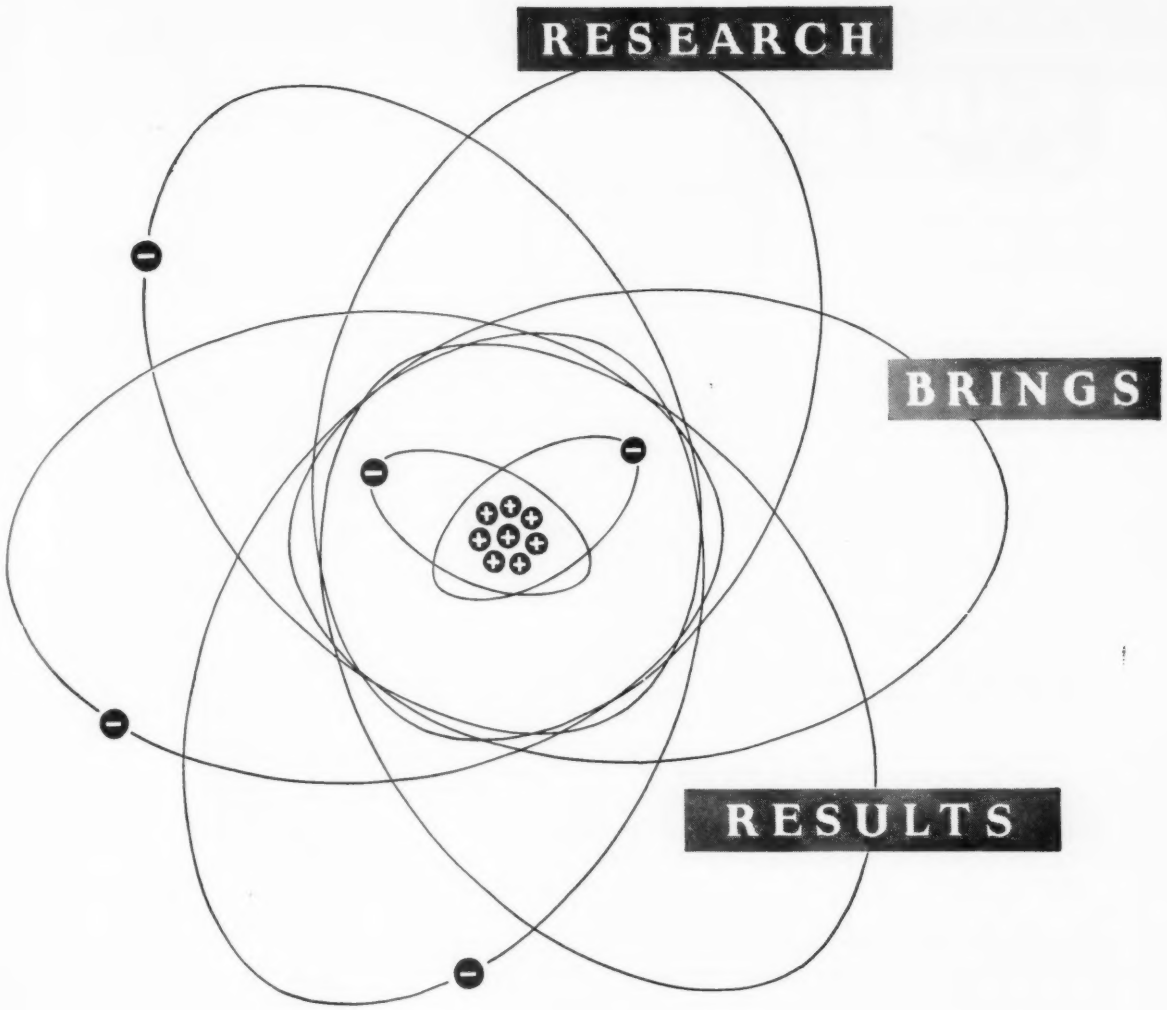

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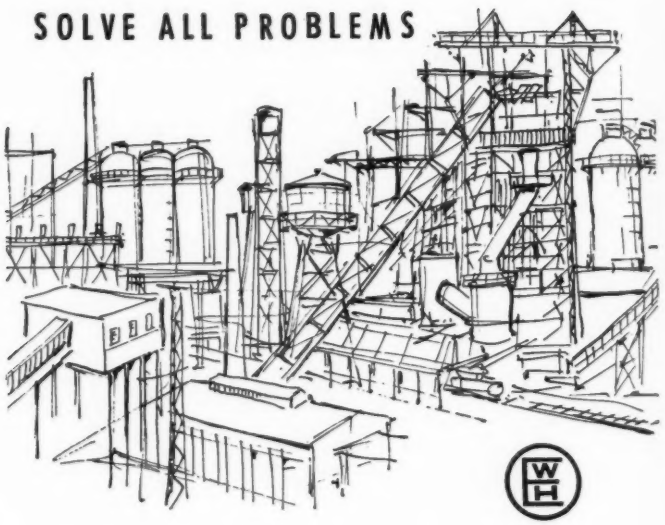

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FOR THE

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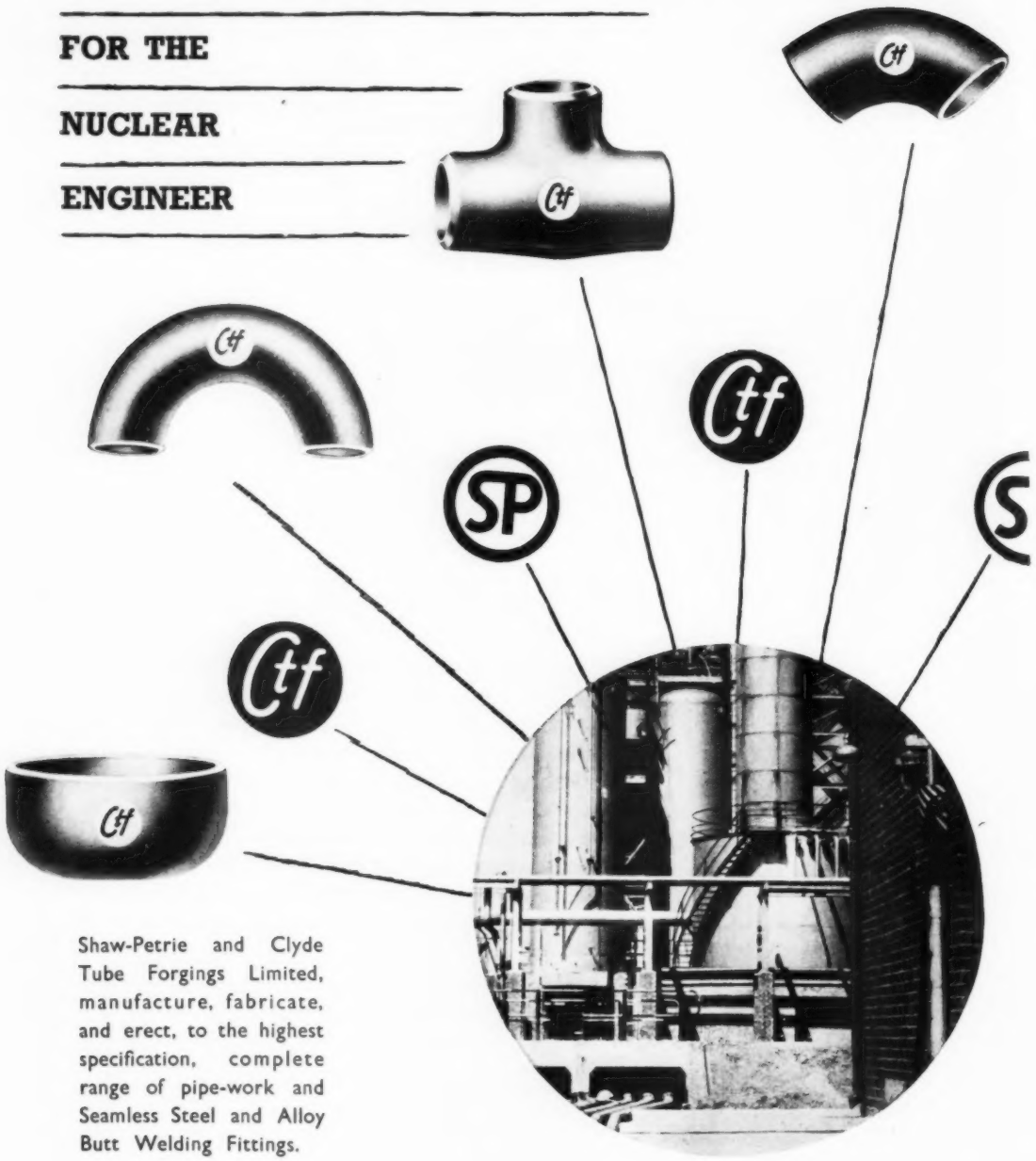

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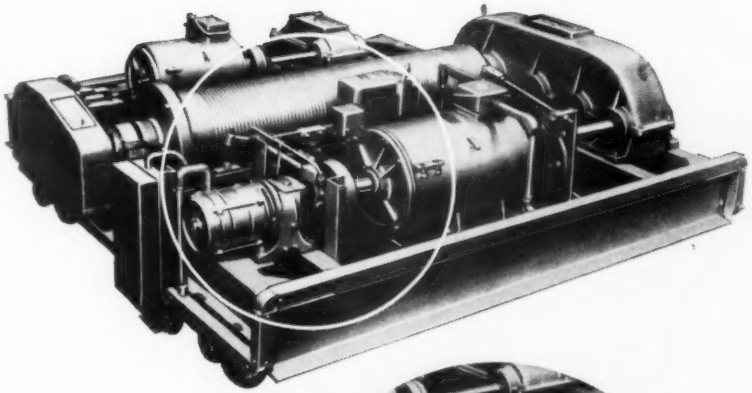

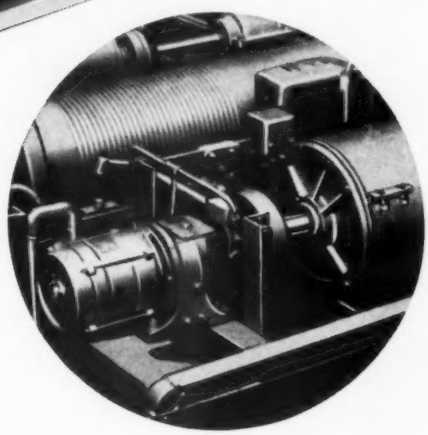

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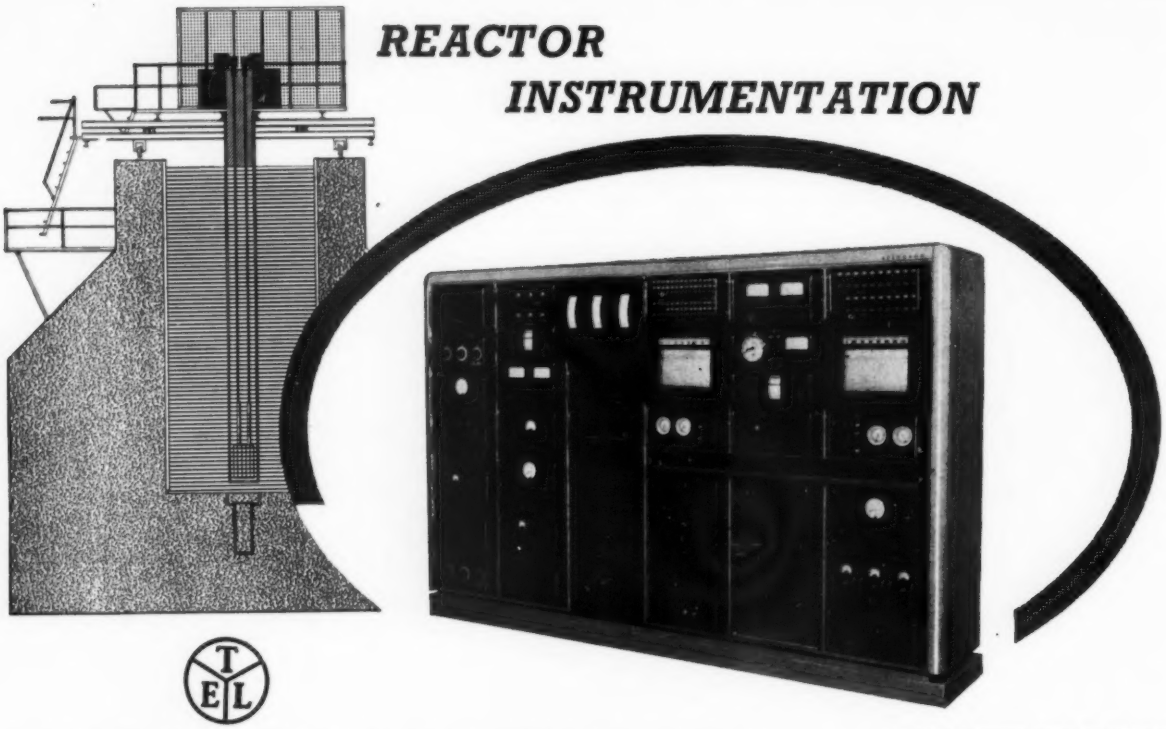

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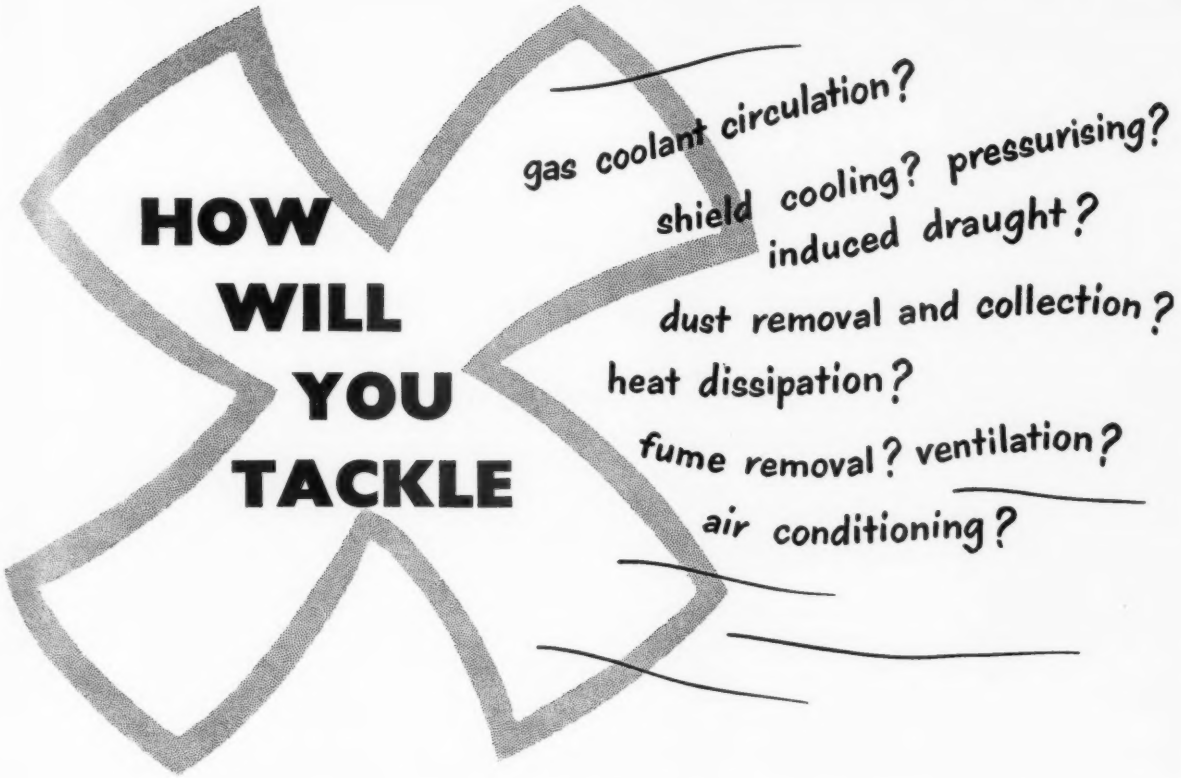

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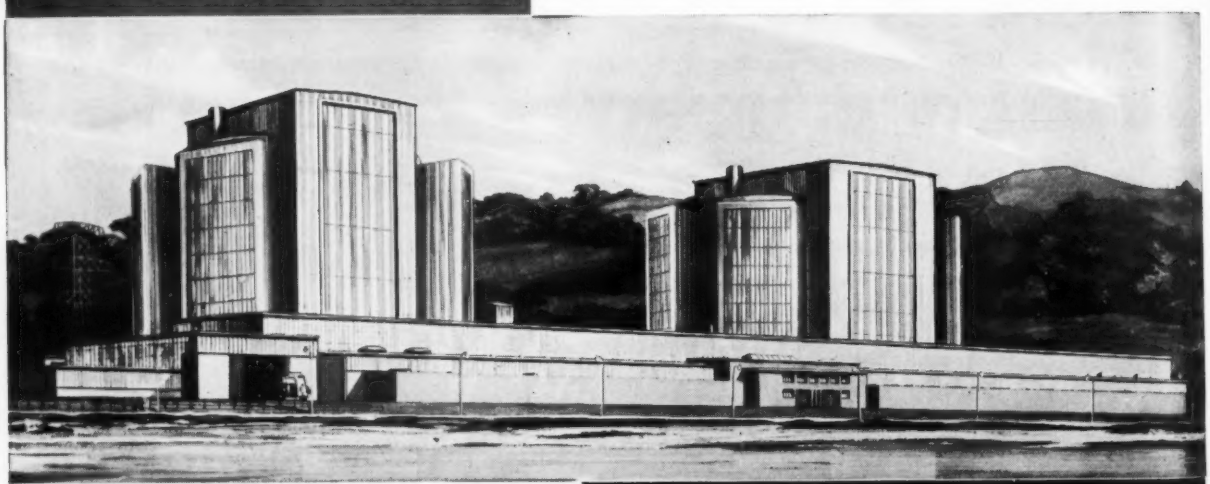

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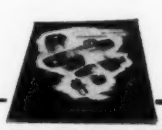

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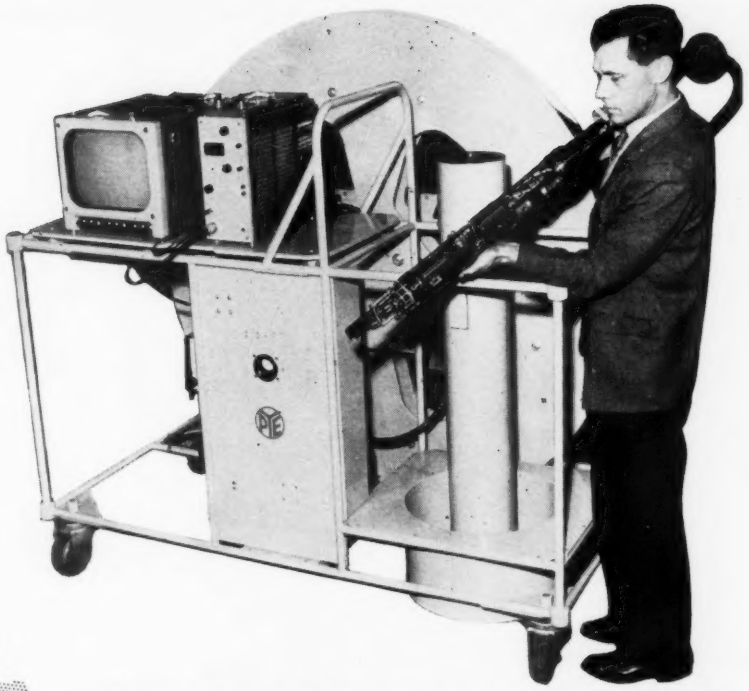
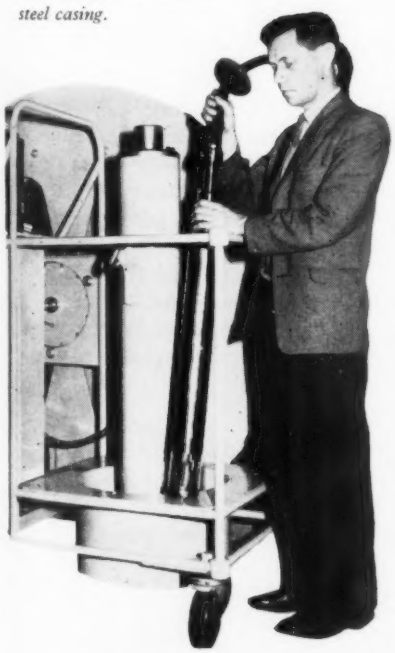


The special camera is shown here without its stainless steel casing. Beside it is the trolley with control unit, monitor and cable.

INDUSTRIAL TELEVISION at CALDER HALL

This illustration shows the camera in its stainless steel casing.



After demonstrating industrial television to the Atomic Energy Authority last year, Pye Limited were given a contract to design a special camera capable of being used inside an atomic reactor at the Authority's Cumberland factory. This has now been completed and has been delivered to Harwell for tests prior to its use at Calder Hall. For ease of manipulation, the camera carries its own source of illumination consisting of a series of four small but powerful bulbs grouped around the camera's lens. In addition, a remotely controlled rotatable mirror enables all-round viewing to be obtained.

As the equipment is to be used while the atomic pile is dangerous, the camera can be remotely controlled and is housed in a thin stainless steel casing 3½ inches in diameter and 30 inches long. The whole apparatus, involving the camera and its 75 feet of cable, the control unit and the monitor, is mounted on a trolley so that it is ready for instant use. As the camera is liable to be exposed to temperatures of up to 200°C, the control cables leading to the camera head are enclosed in a flexible hose through which carbon dioxide is pumped to cool the cables and camera. Radio-active dust can be removed from the camera, after its withdrawal from the reactor, by washing down.

A second camera, which is now being made, is to be supplied to the Authority within the next few months and will be used as a standby.

Wherever it is too difficult or too dangerous to use a human observer, Pye Industrial Television comes into its own. In diverse uses as far apart as whaling ships and opera houses, Pye Industrial Television is increasing efficiency and cutting costs. Your firm may have a use for it. Write to Pye for further details or a demonstration.

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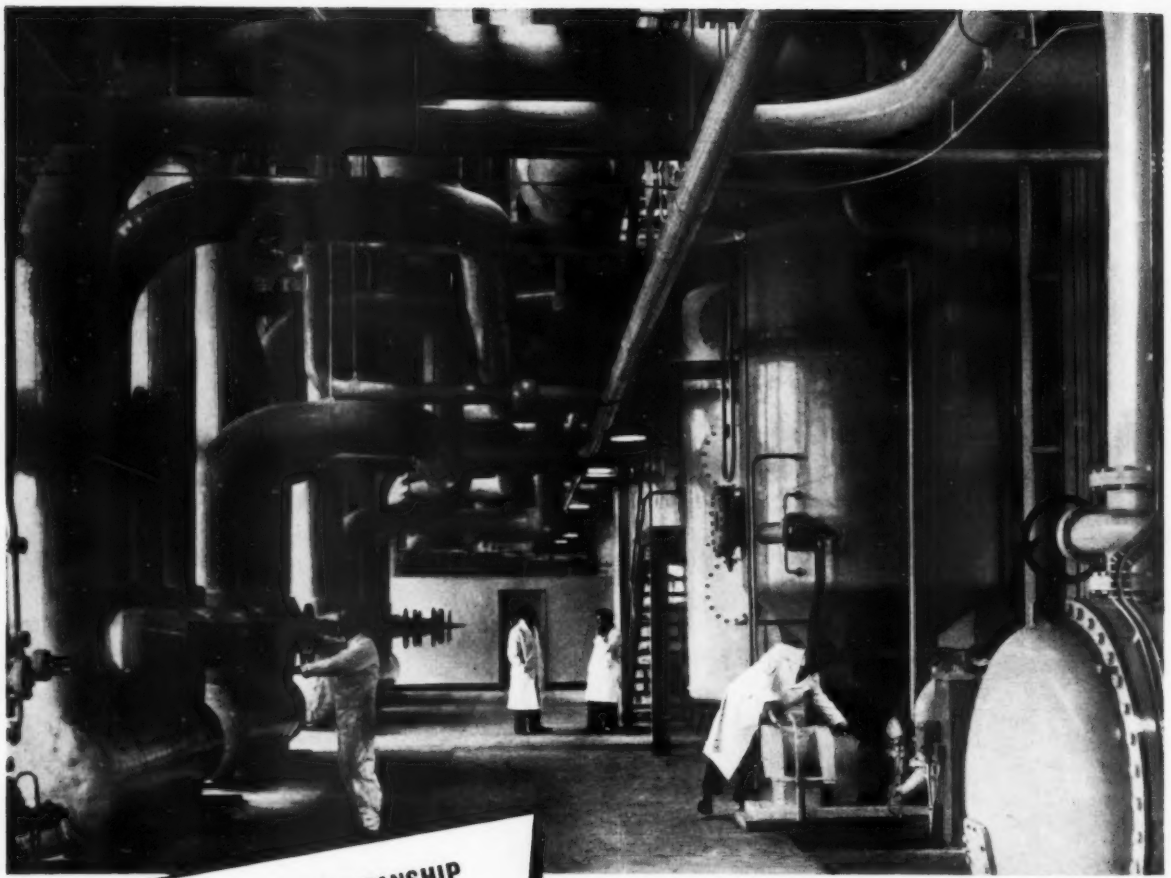

The basement of the turbine hall of Calder Hall A Station
Courtesy of the United Kingdom Atomic Energy Authority

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The main steam pipework at Calder Hall nuclear power station conveys over half a million pounds of superheated steam per hour between the heat exchangers of a reactor and the turbines.

The turbines are supplied simultaneously with high-pressure steam at 185 lb. per square inch and 590 F., and low-pressure steam at 38 lb. per square inch and 340°F.

The pipework and steam receivers for this section of the nuclear power plant were made in Derby by Aiton & Co. Ltd., and were subjected to strict quality control during every stage of manufacture. Every butt-welded joint, for example, was examined by gamma-radiography, with Iridium-192 sources and Kodak X-ray Film.

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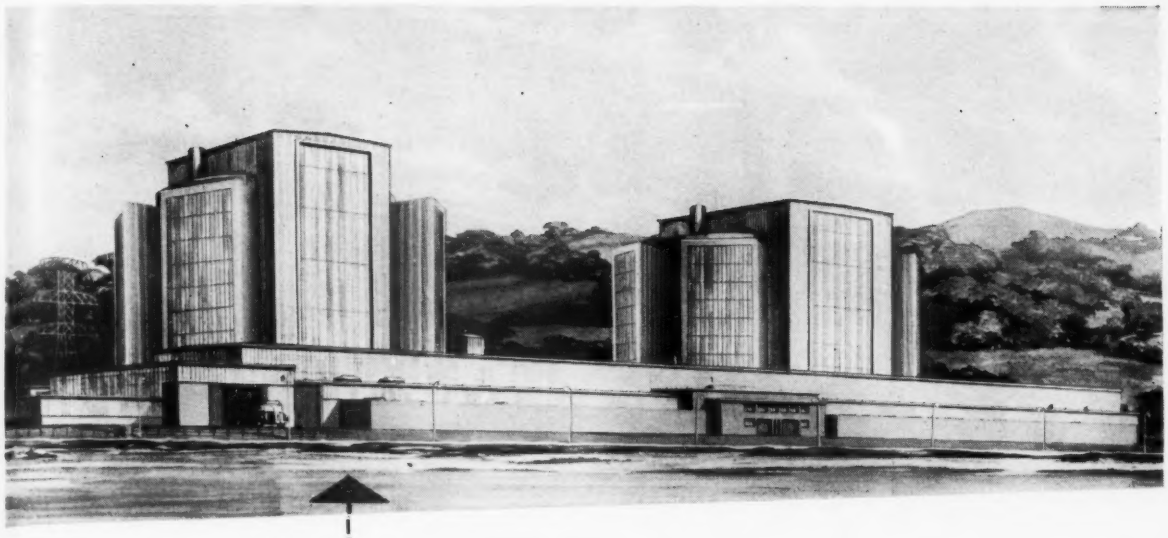

For the South of Scotland Electricity Board

The full resources of the Group are being brought to bear on the construction of a 320 MW nuclear power station.

For the United Kingdom Atomic Energy Authority

The Motherwell Bridge & Engineering Company Ltd. (a member of the Group) is building at Dounreay, Scotland, the reactor-containing sphere for the world's first fast breeder reactor. The G.E.C. is installing the electrical generating plant.

Shaping the pattern of the nuclear future

The G.E.C.—Simon-Carves Atomic Energy Group is already engaged in two major nuclear power projects of world significance.

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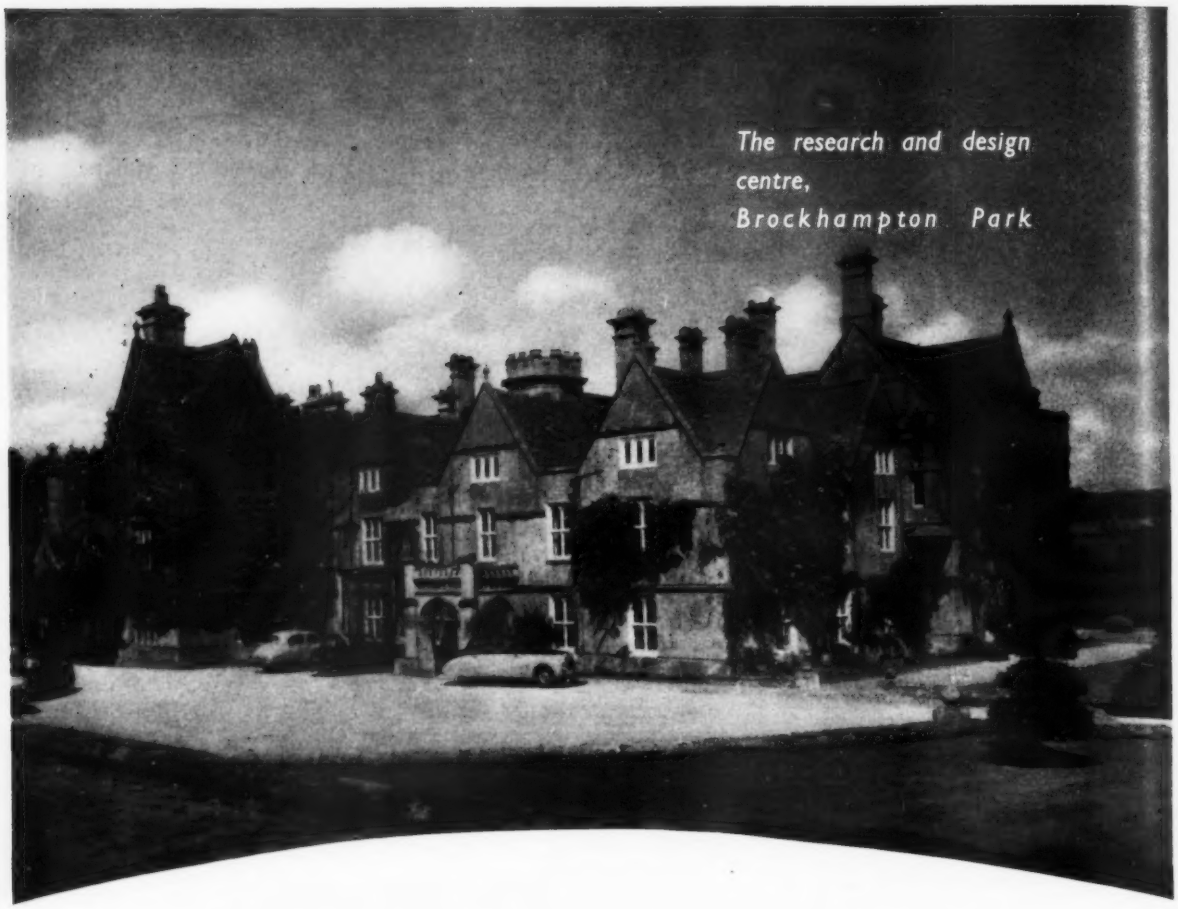

The research and design centre, Brockhampton Park

REACTOR INSTRUMENTATION

Dowty Nucleonics Ltd. are to supply equipment for the detection of faulty fuel elements in the Berkeley Station.

The design has been carried out at Brockhampton Park in collaboration with the A.E.I.—John Thompson organisation, and production will be backed by the resources of the Dowty Group.

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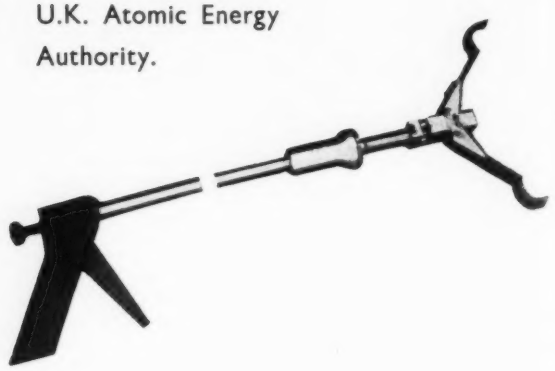

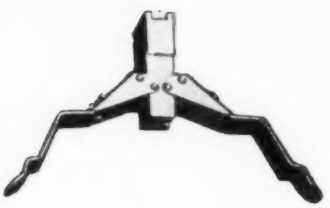

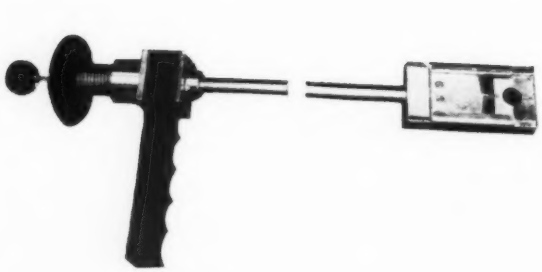

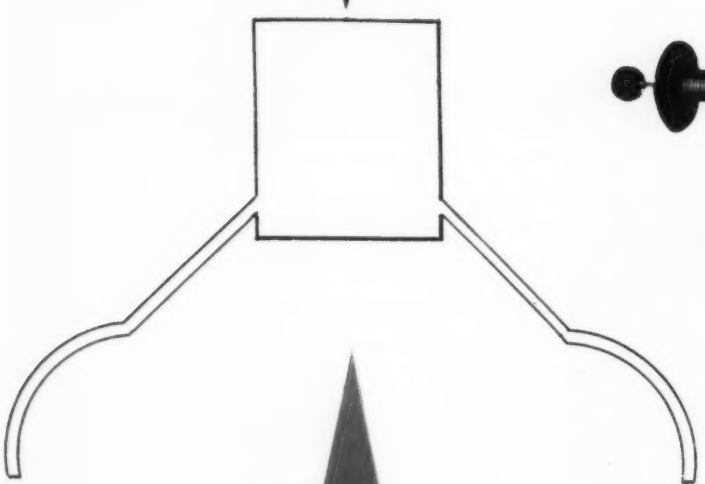

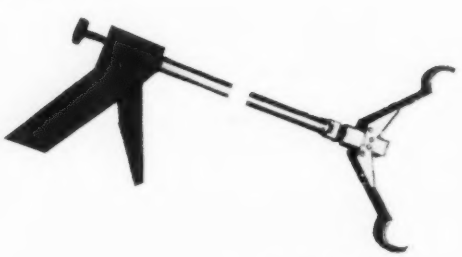

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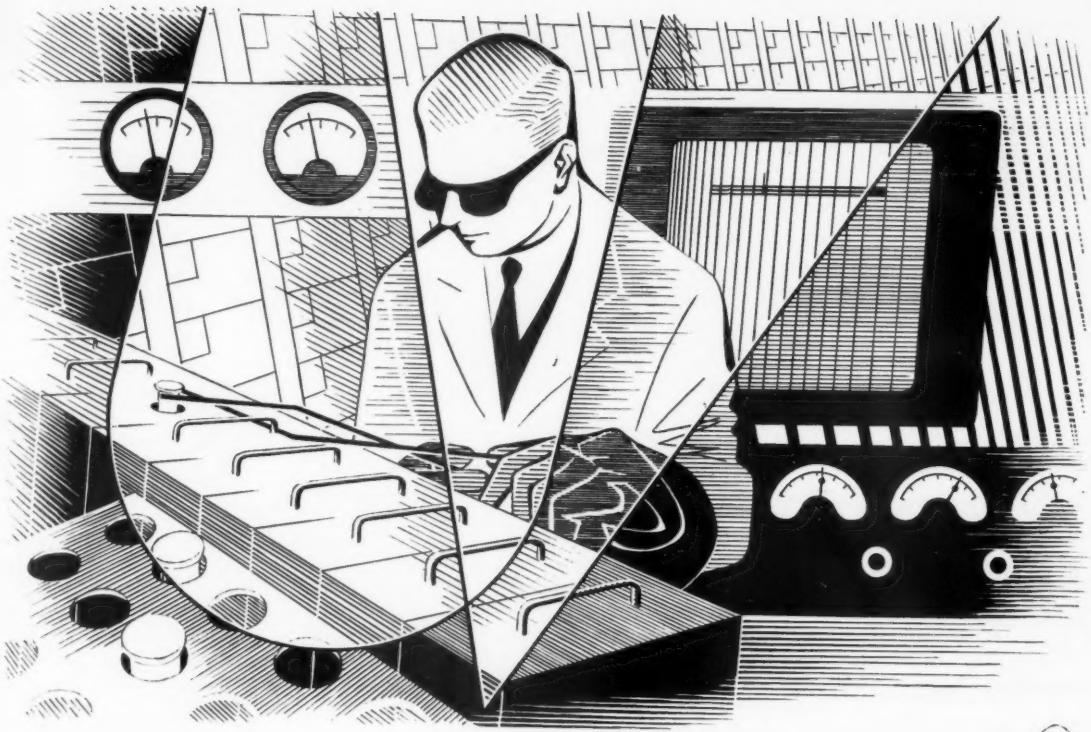

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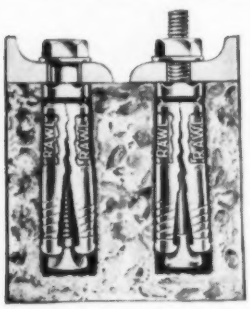

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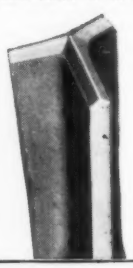

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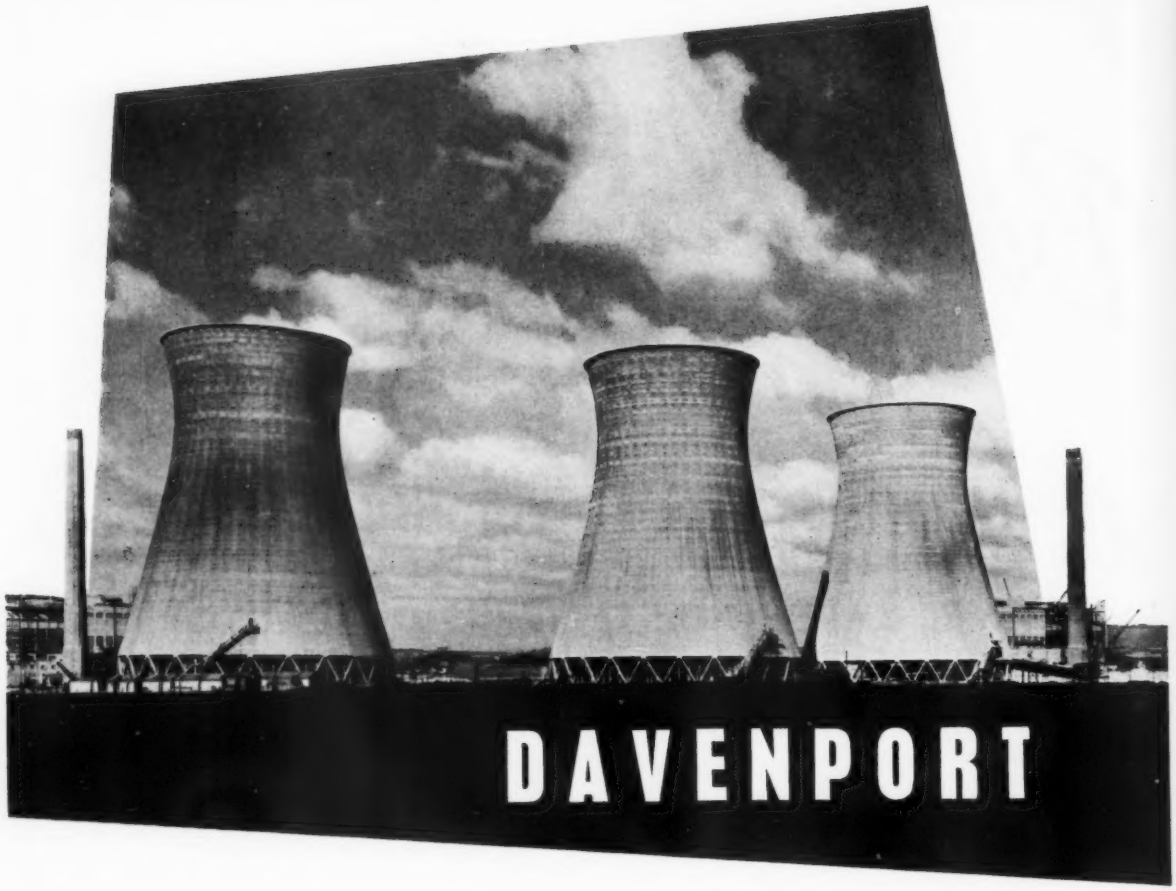

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Murex at Calder Hall Nuclear Power Station

Murex electric arc welding electrodes are being extensively used by the United Kingdom Atomic Energy Authority and we are proud of the fact that they have helped in the construction of Calder Hall, Britain's first nuclear power station and the first in the world to supply substantial quantities of electricity to a national system. For such applications only electrodes of the highest quality can be used.

Murex electric arc welding equipments are also being extensively used in the construction of Britain's various atomic energy plants. These products backed by the resources of the Murex organisation are at your service.

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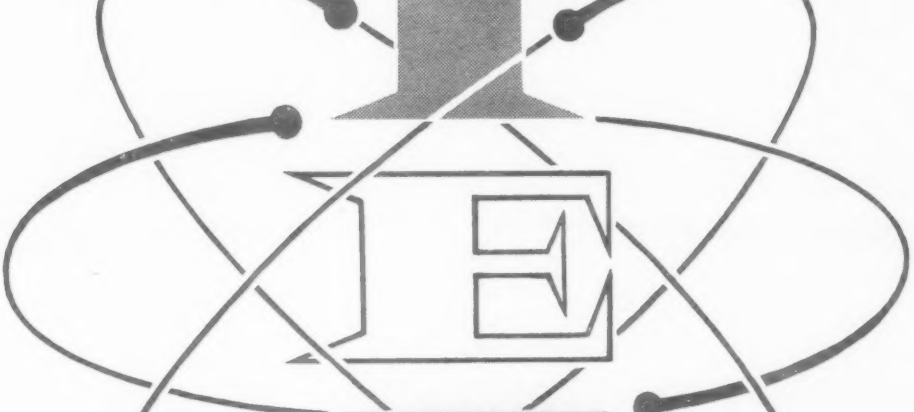

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- The British Lampblown Scientific Glassware Manufacturers' Association
- The Drawing Office Material Manufacturers' and Dealers' Association
- The Scientific Instrument Manufacturers' Association of Great Britain

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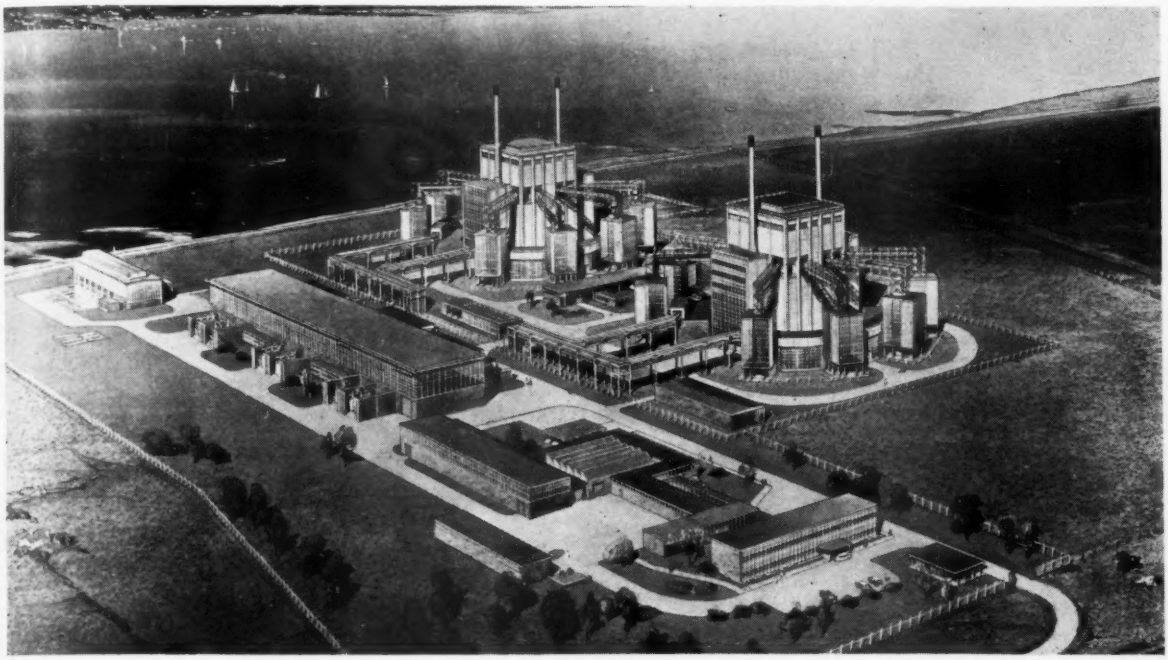
Power Plant for Britain's first commercial Nuclear Power Station



Metropolitan-Vickers is to supply the complete turbine-house installation for the first British Commercial Nuclear Power Station at Berkeley, Gloucestershire, now under construction by the A.E.I. John Thompson Nuclear Energy Company Ltd. Four 80 MW 3,000 r.p.m. mixed-pressure, close-coupled tandem-compound turbine-generators will be manufactured at the Trafford Park Works.

In addition the Company will supply the whole of the associated heat exchange equipment. This will be manufactured at the Germiston factory, Glasgow, which specialises in this type of work. It will consist of four main condensers and four sets of low-pressure feed-water heating equipment, two sets of dumping condensers and associated items, complete circulating water pump house equipment, air exhausters, and extraction pumps.

All this equipment is being supplied by a Company which has more than 50 years' experience in the design, manufacture and operation of thermal power plant.

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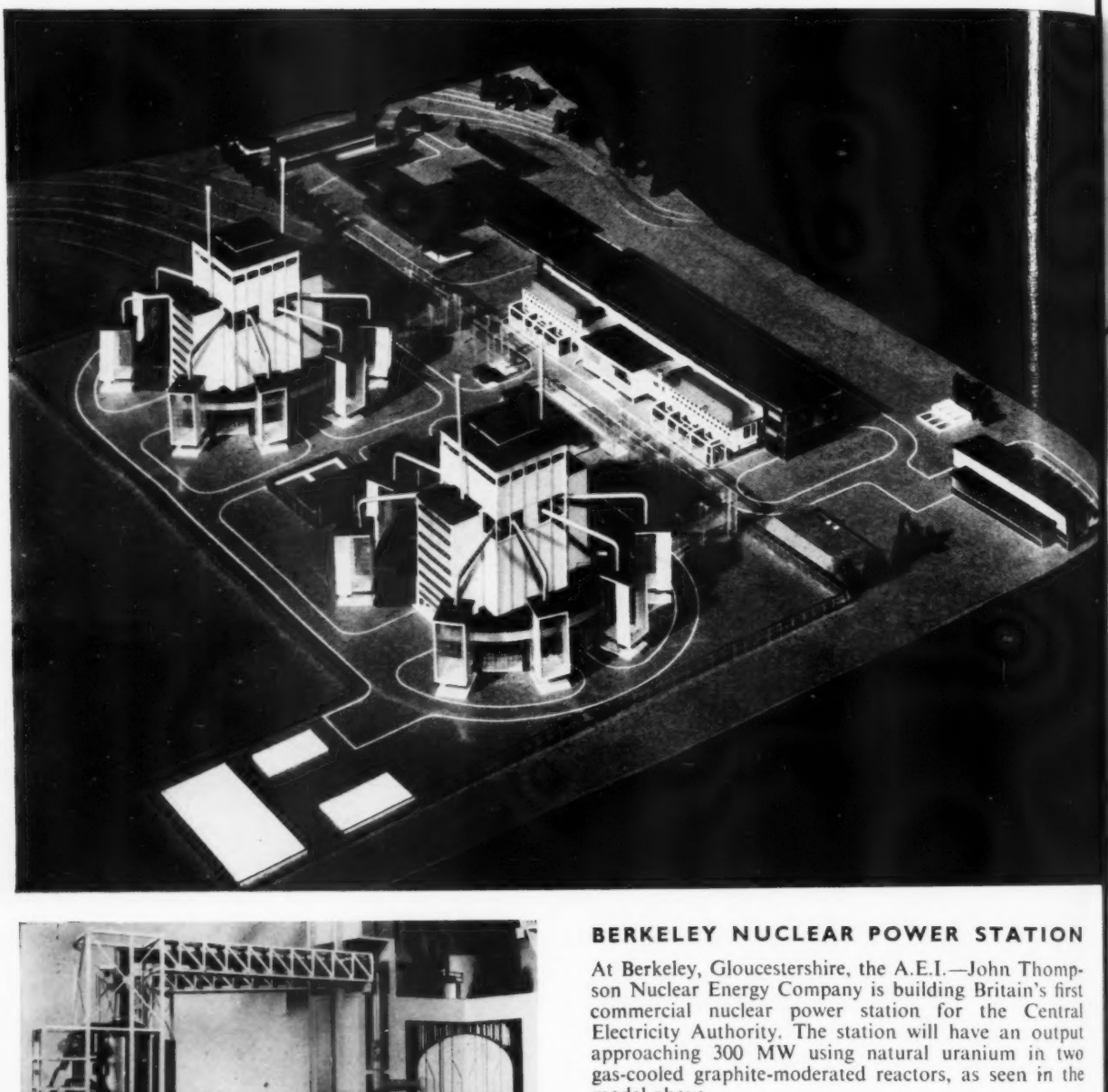

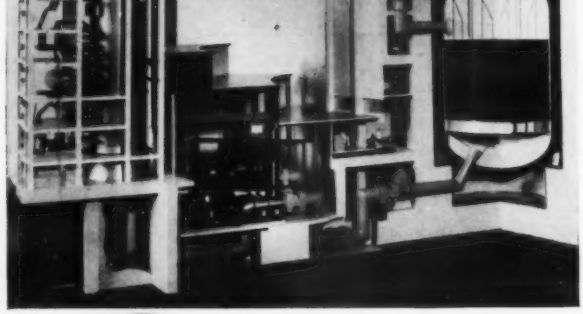

BERKELEY NUCLEAR POWER STATION

At Berkeley, Gloucestershire, the A.E.I.—John Thompson Nuclear Energy Company is building Britain's first commercial nuclear power station for the Central Electricity Authority. The station will have an output approaching 300 MW using natural uranium in two gas-cooled graphite-moderated reactors, as seen in the model above.

John Thompson are constructing the 1000 ton reactor vessels of 3 in. steel, the fuel handling machines, gas-cooling circuits, the sixteen large heat-exchange towers and the thermal shielding of 4 in. steel. 150 miles of tubes will be used in the heat exchangers alone.

The sectionalised model at left shows one reactor and one of the heat-exchange circuits.

JOHN THOMPSON GROUP

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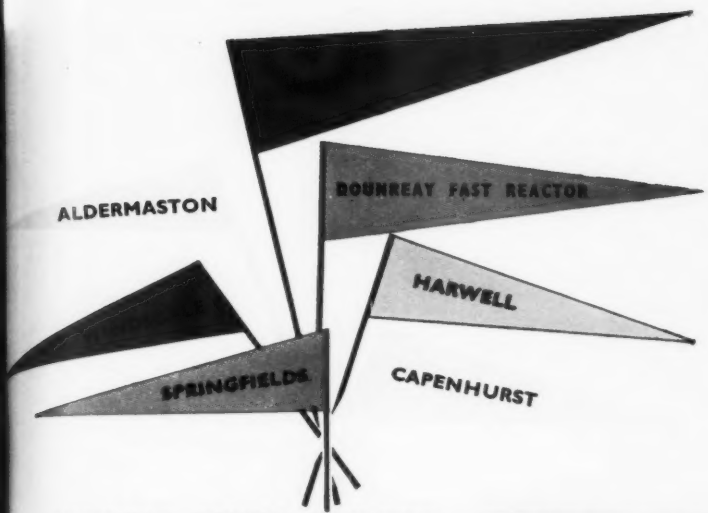
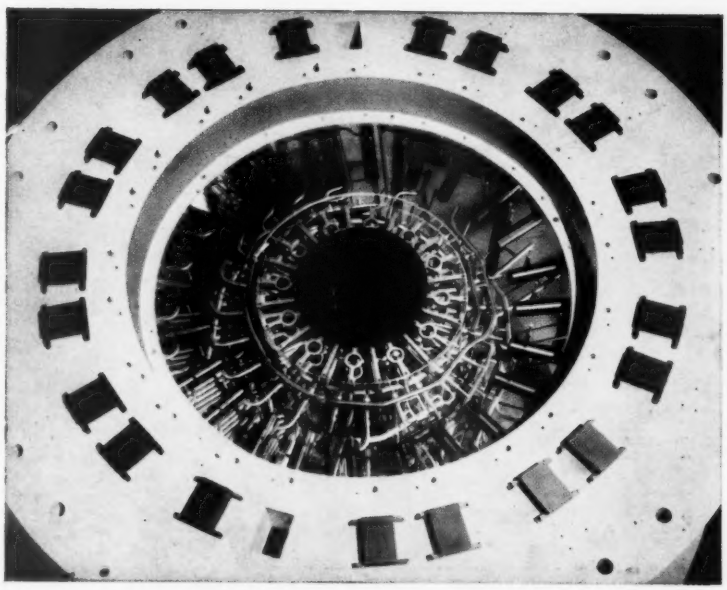


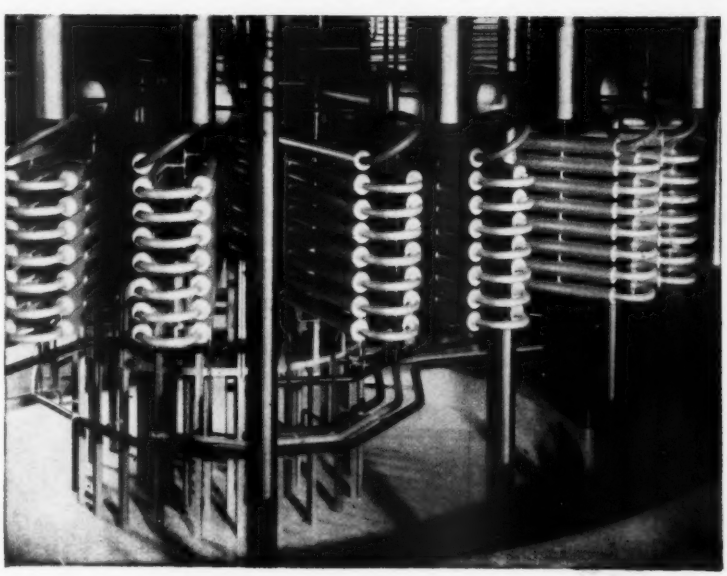
Probably the most complicated stainless steel vessel produced in Britain—the reactor vessel being made by John Thompson for the U.K. Atomic Energy Authority's full scale fast breeder station at Dounreay.

NUCLEAR POWER PROGRESS

The construction of Britain's first commercial nuclear power station by the A.E.I.—John Thompson Nuclear Energy Company Ltd. marks a further step forward in nuclear progress. Since the earliest days of nuclear experimentation, John Thompson have produced the requisite plant. For the Ministry of Supply and later the U.K. Atomic Energy Authority they have executed work to exacting standards at Springfields, Windscale, Harwell, Capenhurst and Dounreay. With Associated Electrical Industries in the A.E.I.—John Thompson Nuclear Energy Company, formed to produce atomic power plant for the world, they are producing research reactors for the Atomic Weapons Research Establishment, and for the West German Government, and now the first full-scale commercial station for the Central Electricity Authority.

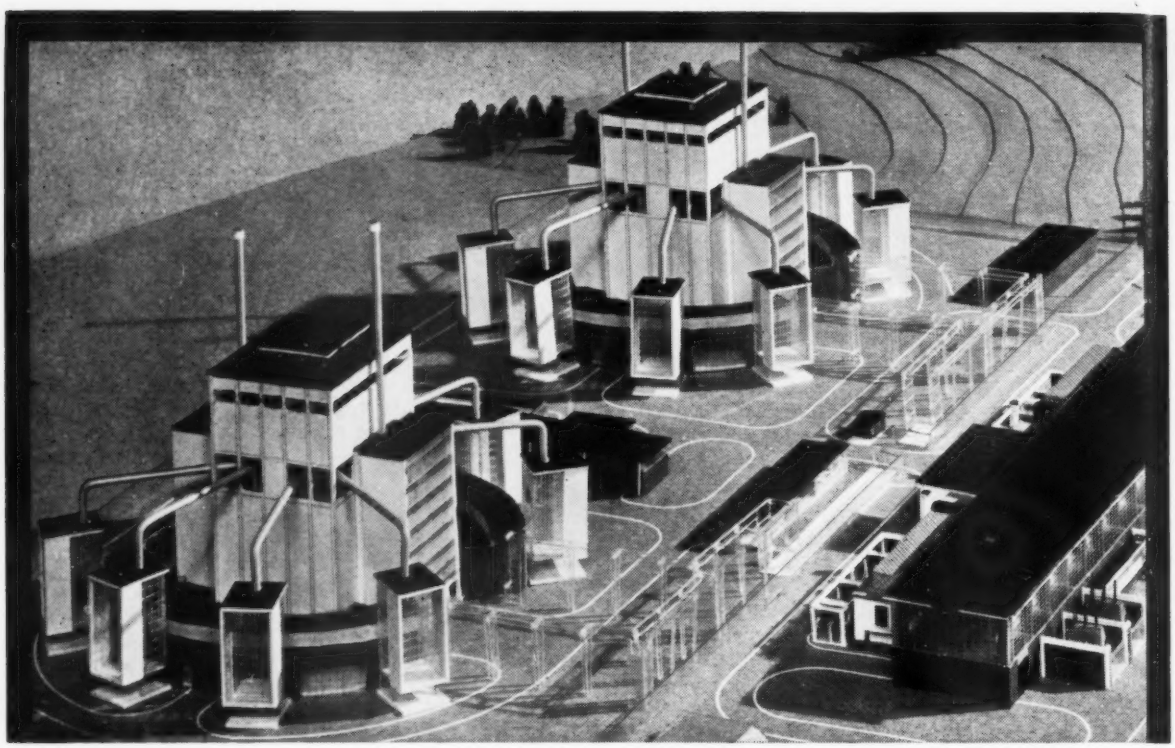
John Thompson companies are proud to be associated with the A.E.I. in this successful nuclear power team, capable of producing research reactors and atomic power stations for Britain and the World.





DOUNREAY FAST REACTOR

This scale model of the primary heat-exchange section of the Dounreay fast reactor was produced by John Thompson to aid the design and construction of liquid metal circuits and heat-exchangers which they are producing, together with the reactor vessel, secondary heat-exchange and boiler plant for the U.K. Atomic Energy Authority's full scale fast breeder station.



Nuclear power for Britain

SUNVIC CONTROLS LIMITED are undertaking (on behalf of the A.E.I.—John Thompson Nuclear Energy Company) the design and supply of the reactor and heat-exchanger instrumentation and the burst slug detection equipment, for the first commercial nuclear power station in the world. This power station is now under construction at Berkeley in Gloucestershire.

THE COMPANY are also engaged in instrumentation for the three Research Reactors for Associated Electrical Industries Limited, the Atomic Weapons Research Establishment, and the Government of West Germany. The Company are also experienced in other process control fields—notably in the oil and chemical industries.

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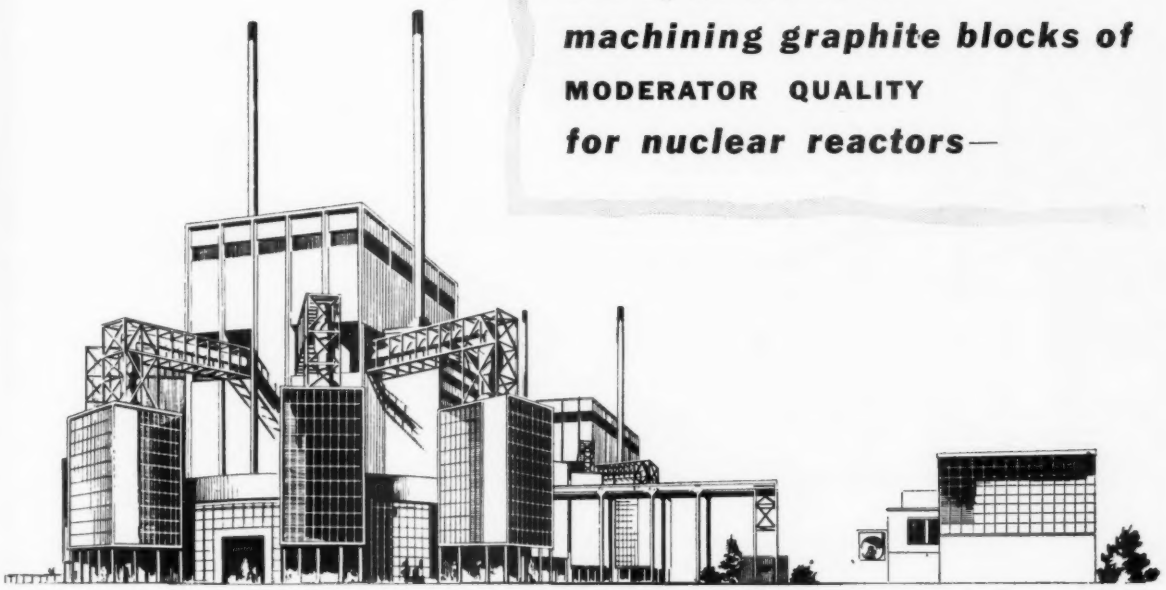

—and will be machining the graphite moderator blocks in the reactors of the Berkeley Power Station

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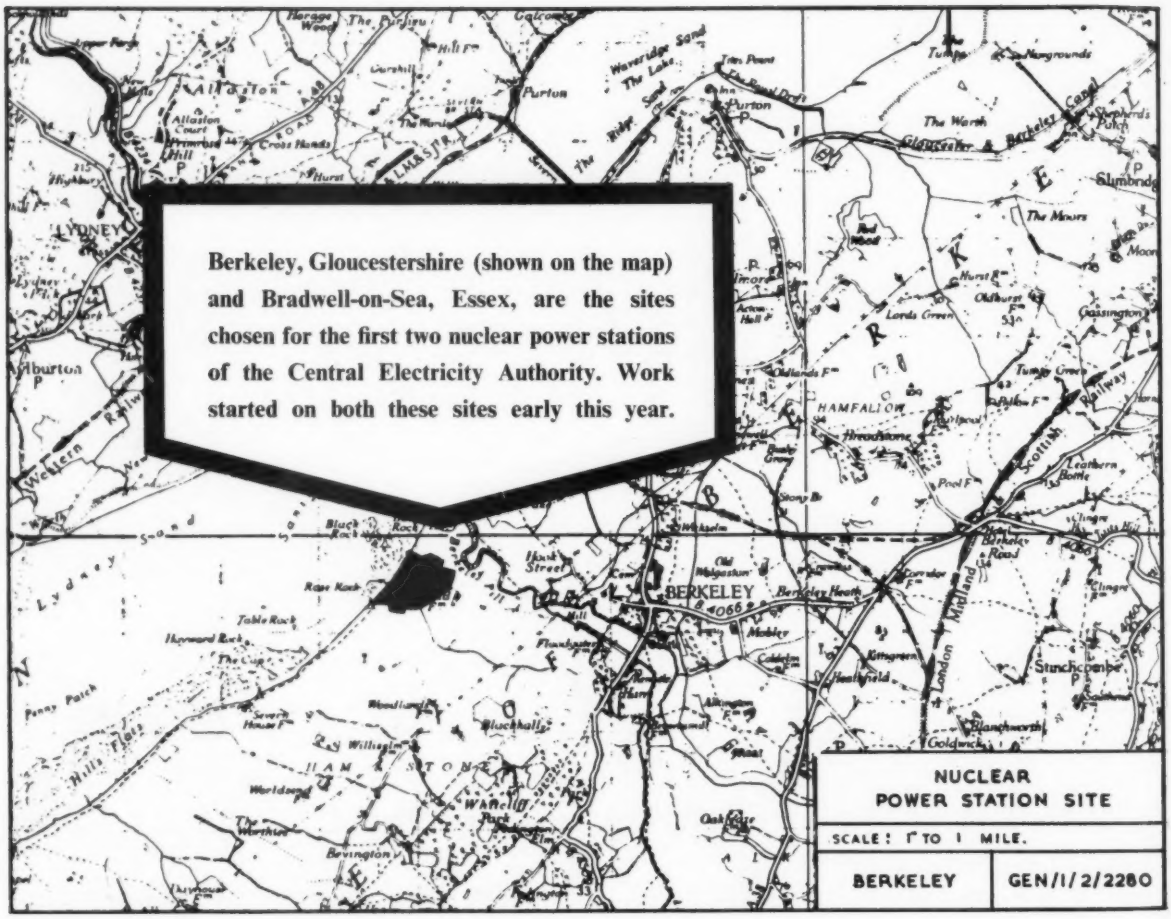
Electricity from Nuclear Energy


Berkeley, Gloucestershire (shown on the map) and Bradwell-on-Sea, Essex, are the sites chosen for the first two nuclear power stations of the Central Electricity Authority. Work started on both these sites early this year.
BERKELEY
HAMFALLON
NUCLEAR POWER STATION SITE
SCALE: 1" TO 1 MILE.
BERKELEY
GEN/1/2/2280

The growing need for power

As Britain's industrial efficiency increases, so does the need for power. The demand for power doubles every ten years; supplies of home-produced coal do not keep pace with these developments. Nuclear energy will do much to make up the discrepancy between the demands for electric power and the available coal supplies.

Central Electricity Authority have placed contracts for two nuclear power stations, sited at Bradwell in Essex and Berkeley, in Gloucestershire. Negotiations are proceeding for a third station which, subject to consent, will be erected at Hankley Point near Bridgwater in Somerset. These three stations will have an aggregate capacity of some 850,000 kilowatts.

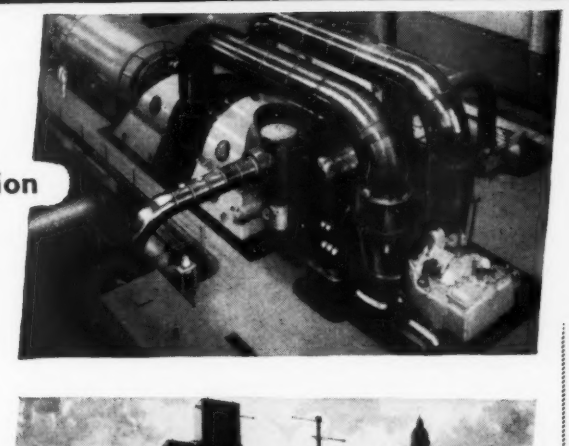
The Government's revised nuclear power station programme provides for 19 nuclear power stations to be completed by 1965. They will develop from 5,000 to 6,000 megawatts of capacity and add to the national power resources the equivalent of some 18 million tons of coal a year.

As the demand for power grows, nuclear energy will become more and more important as a source of electric power, upon which the economic future of the country so largely depends.

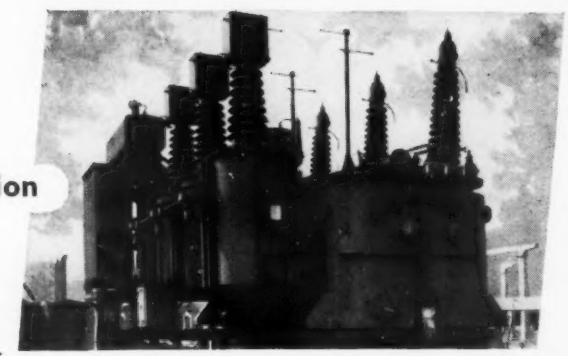
CEA

B
T-H

ELECTRICAL EQUIPMENT



Generation



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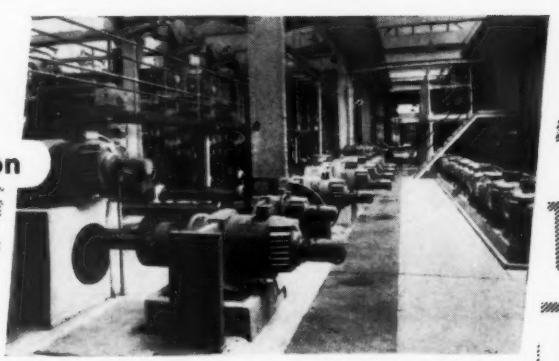

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April 1957 Volume 2 Number 12

The Queen and Prince Philip spent a day at Harwell last month. In addition to the reactors DIDO and LIDO, the plutonium laboratory and the main workshops, they were shown some experimental work on controlled thermonuclear reactions. Here seen with Dr D. Littler, Head of the Reactor School, the Queen is evidently amused by a Burmese weapon presented to the school by some old students who described it as a 'neutron chopper.'

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Nuclear Power
The journal of British nuclear engineering

	Leader	125
	Worldview	127
	Hermes—electromagnetic isotope separator	132
LYNOTT	**Transformer design trends**	135
LEE	**Glove box symposium report**	139
	Construction progress at Berkeley	142
	Berkeley full-colour supplement	facing 142
	Slave manipulator for hot cells	144
CAMERON & AUSTIN	**An electronic reactor simulator**	146
NICHOLLS & SPENCE	**Fuel processing**	152
	Equipment	155
HILL	**Reactor physics—11**	157
	Books	161
	Companies	162
	Names in the News	164
	Institutions, Publications	165
	Research Reports, Programme	166
	Index to advertisers	facing inside back cover

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Consulting Engineers : W. S. Atkins & Partners

Civil Engineering Progress at Berkeley

THE SITE AT BERKELEY on the Severn Estuary has been compared with a wartime invasion beachhead, and like a major military campaign, 'Operation Berkeley' has been planned to the last detail. It went into action on time—without delay and without fuss. From the start, it has been characterised by enthusiasm and team work, a real sense of urgency matched by a real will to win.

Civil engineering work for this new atomic power station is progressing fast. In seven weeks bulk excavation for the first reactor—an area as big as Piccadilly Circus—was completed and the concrete foundations have commenced. Excavation for the second reactor is also well under way. Another vast filling and earthmoving job—raising the general site area by as much as 13 feet in places to above highwater level—is being pushed ahead at the same speed.

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Nuclear Power
THE JOURNAL OF BRITISH NUCLEAR ENGINEERING
APRIL 1957 VOLUME 2 NUMBER 12

How round was my number

LORD MILLS' announcement of the revised British power programme of 6000MW (net) by 1965 really asks more questions than it answers. The figure was in fact produced, as it were, from a hat, and like all good conjurers Lord Mills did not allow us to see how the trick was done. Simple arithmetic however shows that he did well to stress the flexibility of the plan, for further revisions seem inevitable. Working on the meagre information made public, let us see what the programme might mean. Of the nineteen stations scheduled, three have been announced with a combined minimum guaranteed net output of 875MW. This figure is however likely to be nearer 960MW in view of the turbine plant being installed. We are thus left with about 5040MW to be obtained from 16 stations, or an average of 315MW per plant. However, Lord Citrine has stated that the second-round stations will probably have net outputs of about 500MW and Sir John Cockcroft recently mentioned 800 or even 1000MW from a single station in the later stages of the 1965 programme. Thus it is clear that not all the nineteen stations are to be large base-load ones and that some are probably comparatively small plants intended for meeting peak demands. The development of such reactors is a pressing necessity but as to the type and number of these, we are still left guessing. Probably no one knows the answer to this yet, but the Government should have said so.

Another mystery is the rate of construction. Nineteen stations in eight years spread over four or five contracting groups works out at about one station per group every two years. Now it has been stated publicly by two of the groups that they are able and prepared to begin a new station every year if required. This presumably means that either these groups are only going to be used at about half their capacity or that they also hope to export one complete station every other year. If the former is the case, it would be interesting to know the reason: is it material shortages or is it lack of investment capital? In other words, is the programme the best we can do physically or is it what we can afford, taking into account other pressing demands for capital investment?

Obviously, in view of the gigantic Euratom programme manufacturers' eyes must be fixed on the Continent and it is good that the British programme will allow scope for exports. Lord Chandos said recently that he doubted if there was much hope for complete packaged deals of natural uranium reactors since most countries in a position to need this kind of plant were capable of building much of it themselves, provided they have the detailed technical assistance and certain highly specialized components. If this view is tenable—and no convincing case has been made against it—it would seem that an export market in reactor knowhow and components can be built up without seriously affecting the domestic programme by cutting into supplies of steel and other materials.

We are thus left with an uneasy feeling of still not knowing where we are going. The 1955 programme at least gave some indication of the types of station to be built: the 1957 one just produces a nice round number and leaves it at that.

In his Stockholm speech last month, Sir Christopher Hinton said manufacturing provision must be laid down on the basis of forecasts and could not follow in the wake of technical development. This 6000MW plan is simply not good enough to allow realistic forecasting.

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UNITED KINGDOM

UK to build 19 stations in 8 years

Great Britain is to have 6000MW of nuclear capacity in operation from 19 stations by the end of 1965. This is the substance of the Government's long-awaited revised power programme which was announced in the House of Lords on March 5 by the Minister of Power. Lord Mills said Britain was already spending £250m a year on imported fuel —chiefly oil—and this burden on our balance of payments would continue to grow. The Government's task had been to consider how the 1955 White Paper programme (1500—2000MW from 12 stations by 1965) could be accelerated in view of the success of Calder Hall and other recent technical advances. His expert advisers had now completed a study of the situation and were of the opinion that the English and Scottish electricity authorities could reasonably aim at a minimum figure of 5000MW, but that if technological development continues favourably and financial resources can be found, 6000MW should be reached by 1965. The Government had therefore decided, with full agreement of the CEA, SSEB and the AEA to plan raw material supplies, site acquisition and transmission networks on a scale sufficient to reach the 6000MW figure during the next eight years. The actual amount of capacity installed will be subject to technical experience and development and to the availability of physical and financial resources.

Achievement of the 6000MW programme would save 18 million tons of coal in a full year's working, but it would also mean a large increase in the electricity undertakings' annual investment programme and a heavy burden on the nation's capital resources. On siting, the Minister of Power said the programme would undoubtedly raise problems but he was confident that it could be carried through without serious interference with the amenities of the countryside or with the rights of individuals. He said Mr Reginald Maudling, Paymaster General, who represents his Ministry in the Commons, would be tabling amendments to the new Electricity Bill to take account of this.

Speaking later at a Press conference attended by Lord Salisbury, Mr Maudling, Lord Citrine and Sir Edwin Plowden, Lord Mills said the 6000MW programme would involve a total of 19 power stations (not necessarily on 19 sites and not including the Northern Ireland station) costing £919m at present estimates. Of this £742m would represent capital expenditure on the stations and £177m for the initial fuel charge. On completion of this programme, aggregate installed nuclear capacity would represent 15 per cent of the total but because of its higher load factor, it would supply about 25 per cent of the country's needs. Lord Citrine, CEA chairman, said the output of the second-round stations might well be 500MW each as opposed to the 300MW of the first stations. AEA chairman Sir Edwin Plowden added that slightly enriched fuel would probably be available for stations coming along in the later stages of the programme. It is not intended to issue a White Paper on the new plan since it is flexible and not meant to be a rigid schedule. The British home programme had been designed so that it would not absorb the country's entire productive capacity, thus allowing firms scope for export of plant.

US-UK team win first power reactor

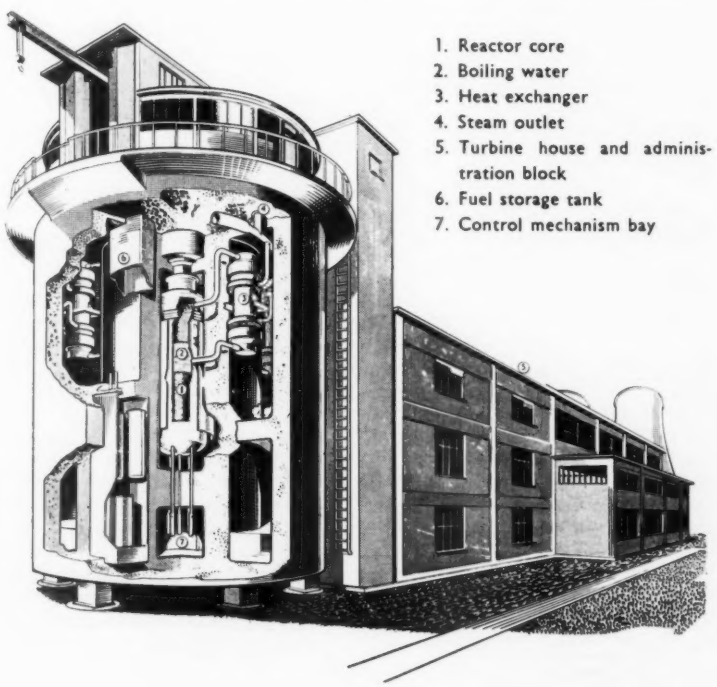
The Federal Republic of Germany's first power reactor is to be a joint US-UK plant. Speaking in London on March 19, F. G. Mitchell, chairman of Mitchell Engineering Ltd, announced that Rheinisch-Westfalisches Elektrizitätswerke AG had just placed an order for a 15MW (elec) closed-cycle boiling-water reactor with AMF Atomics Inc, New York, in association with his firm. He said the value of the order for the nuclear work would be $5.3m of which Mitchell's share would amount to about $3m. The turbine power plant would be German as would the civil engineering and building. The fuel—uranium enriched to 2-9 per cent—will come from the US and the initial charge will be worth $1.5m.

The reactor is of the dual-cycle boiling water type generally similar to that ordered for the Elk River, Minnesota, plant. In this the primary steam exchanges with water to raise non-radioactive steam for the turbine. Natural circulation is used in the primary side but provision will be made for forced circulation should it be required later. Steam pressure at the turbine stop valve will be 600 lb/in^2 dry saturated. In the primary vessel it will be at 900 lb/in^2.

AMF Atomics will supply the core assembly, control gear and instrumentation, while Mitchell will be responsible for the design of the reactor pressure vessel, the primary and secondary heat exchangers, pipe work and containment.

The exact site has not yet been announced. It is likely to be in the Cologne-Düsseldorf area but one in Bavaria has also been mentioned. In carrying out the contract, AMF-MEL will work in close cooperation with Siemens-Schuckertswerke, Erlangen.

Mr Mitchell disclosed that his group had won the contract in open tender against eight other bidders. He said design work would start straight away and construction would begin in July. The plant is scheduled for completion late in 1959. He added that another similar contract was reasonably certain and a third was a distinct possibility. Neither of these would be in Europe. The RWE



1. Reactor core
2. Boiling water
3. Heat exchanger
4. Steam outlet
5. Turbine house and administration block
6. Fuel storage tank
7. Control mechanism bay

contract is believed to be the first power reactor ordered as a result of an international competition. Mr Mitchell said it was a great day for Britain and for his company.

Another reactor for Harwell

A new experimental low energy reactor —NERO—became critical at Harwell for the first time on February 23, and its experimental programme is now beginning. The name is derived from the phrase Na (sodium), experimental reactor, zero energy. It will be used to investigate the physics design problems associated with the more advanced types of graphite-moderated power reactors now under study by the Authority.

The reactor consists of a graphite stack which can be varied in size up to a cylinder of about 14ft dia. by 10ft high within a two-foot thick concrete biological shield. Fuel elements of differing types may be arranged within the graphite stack in a number of possible lattice patterns. The restacking of the graphite to permit a change in the fuel element arrangement can be done in a few days. The reactor is controlled by two vertical cadmium control rods which can be moved into the graphite stack through the top of the biological shield. Cadmium safety rods move into the graphite stack in a similar manner. The maximum thermal neutron flux is about 10^8 neutrons/cm²/sec. and the heat output is restricted to less than a hundred watts.

At first the reactor will be used to check calculations on the effect of separating the fissionable fuel content from the fertile, important in the design of reactors in which the fuel may be recycled. Another application of the reactor is to investigate problems associated with the design study of a sodium-cooled graphite moderated reactor.

NERO was designed and built by an AEA team in association with the following firms: *Saben, Hart and Partners Ltd, London* (Detail design); *Technical Design and Tool Co Ltd, Reading* (Detail design); *March Ltd, Reading* (Steel work fabrication); *R.O.F., Nottingham* (Roof trolleys); *H. M. Hobson Ltd, Wolverhampton* (Control mechanism).

Educating the public

In all its eleven years, the British atomic energy undertaking has not had a single case of injury to personnel due to radiation. This striking point was made by Lord President of the Council, Lord Salisbury, when he was opening an exhibition — *Atoms and Health* — at the Royal Society of Health in London last month.

The exhibition, arranged in cooperation with the AEA, is designed to explain to the layman the nature of ionizing radiations and the fact that they are always present to some degree from natural surroundings. By the use of wall charts, models and apparatus, visitors are able to study the causes and effects of natural and man-made radiation and how protection is arranged.

Lord Salisbury, who was introduced by Dr Albert Parker, the RSH deputy chairman, said ionizing radiations were not mysterious, sinister or particularly new. The dangers were recognized and could be avoided but they must be treated with respect. The exhibition showed the standards of protection that could be obtained and we must be satisfied with nothing less.

Thanking the Lord President, Lord Woolton said that with atomic energy we were on the verge of a new industrial revolution the extent of which none of us could foresee.

ZEPHYR now fast-slow

Harwell now has a fast-slow reactor, a simple modification having resulted in interesting changes to the characteristics of the fast reactor ZEPHYR. This is presumably similar to the experimental fast-slow reactor recently put into operation at AEC's Argonne National Laboratory. Graphite has been substituted for the uranium bars that originally formed the outer reflector in ZEPHYR. The thin inner reflector of uranium still surrounds the plutonium core.

According to an AEA statement, the modified reactor diverged with a critical mass of plutonium very close to that in the uranium reflector system. Because the neutrons reflected back into the inner reflector have been slowed down, ZEPHYR now shows some of the characteristics of a thermal reactor. For instance, experiments have shown that the chain reaction can now be controlled, as in a thermal reactor, by putting an absorber of slow neutrons such as cadmium into the graphite. The AEA stated it was too early yet to predict the applicability of this mixed system to power breeder reactors of the Dounreay type.

NORTHERN IRELAND

N. Ireland station to be 150MW

Lord Glentoran, Northern Ireland Minister of Commerce, announced last month a decision to proceed with plans for an atomic power station in Northern Ireland to be brought into operation in 1963-64. The output would be 150MW from a single reactor and the station, estimated to cost £25 million, will be established and operated by the Electricity Board, who have already arranged for the special training of engineers.

The Northern Ireland Government has been investigating the economics of an atomic power station for a considerable time. From recent British experience the capital cost, including initial fuel cost, can now be estimated more precisely. Taking account of the continuous demand for electricity which will arise from large industrial consumers recently established in Northern Ireland, calculations now show that a sufficient economic load for a station of that size can reasonably be expected by 1963 or 1964.

Another public inquiry

It begins to look as if no nuclear power station will ever be built without a public inquiry. Now the Hankley Point, Somerset, site is to have one. Speaking at a county council conference in Taunton last month, Lord Hylton, chairman of the county planning committee, said the Bridgwater Bay area was scheduled four years ago as agricultural land and so his committee had had to recommend an inquiry so that 19 objectors could be heard. Lord Hylton added he had been informed by the CEA that a second station might be built on the same site about five years after the first one was completed. This is only to be expected in view of Lord Mills' statement that the 19 stations in the 1965 plan would not necessarily be on 19 sites and it is now anticipated that this 'doubling up' will be done at Berkeley and Bradwell in due course.

Meanwhile, the Scottish station is still held up pending a decision on the site by the Secretary of State for Scotland. If, however, the Hunterston site is approved, it is probable that the contractors will be able to catch up with the first two CEA stations because the site conditions here are more favourable.

A-sub named

The name H.M.S. *Dreadnought* has been approved by the Queen for the British nuclear-powered submarine. The first ship bearing this name was built in 1573 and fought against the Armada. The most famous *Dreadnought*, built at Portsmouth in 1906, was superior in fire power and speed to any other ship then afloat and revolutionized warship design. She was described by Lord Fisher as a hardboiled egg 'because it cannot be beaten'.

A prototype nuclear plant for the newest and most revolutionary *Dreadnought* will be built in a land-based hull by Vickers Nuclear Engineering Ltd at their Barrow yard. This company, formed in February last year, comprises: Vickers-Armstrong Ltd. Rolls-Royce Ltd, and Foster Wheeler Ltd. Designed to give the submarine high speed and great range, the prototype pressurized water reactor plant should be ready by

1960. It is known that hopes are also being pinned on the organic-moderated reactor for marine work but this will not affect the *Dreadnought*.

The hull for the sea-going vessel will also be built at Barrow by Vickers.

On March 21 the English Electric Co Ltd announced that it had received an order from the Admiralty for *Dreadnought's* main propulsion turbines and condensers. The order is for two sets: one for the land-based prototype, and one for the sea-going vessel.

£27m more for AEA

In the financial year 1957-8 Government expenditure on peaceful atomic energy will be practically £100m—an increase on last year of about £27m. The Civil Estimates, published on March 16, show a grant to the AEA for works services, plant and machinery of about £56m. Plant and machinery for establishments is put at about £34m while salaries account for nearly £3m. Loans for uranium production are estimated at £7½m.

New research body set up

A National Institute for Research in Nuclear Science has been set up by the Government under the chairmanship of Lord Bridges. Its main object will be to provide, for common use by universities and research institutions, equipment and facilities which would be beyond individual scope. It will not replace the work being done in the universities with Government assistance. Finance will be obtained mainly by grants through the AEA, and the universities will pay only the salaries of their staff using the Institute's facilities.

The Board consists of the following members: Representing the Universities: Sir Philip Morris, Sir James Mountford, Prof N. F. Mott, Prof H. S. W. Massey, Prof J. Diamond, Prof R. L. Peierls and Dr D. H. Wilkinson; Representing the University Grants Committee: Sir George Thomson, J. C. Gridley; Representing the Royal Society: Sir David Brunt; Representing the AEA: Sir John Cockcroft, Sir Donald Perrott, Dr B. F. J. Schonland; Representing the DSIR: Dr H. W. Melville, Prof P. M. S. Blackett.

BELGIUM

Giant atom model for Brussels

Construction has started in Brussels on the British site for the World Exhibition to be held from April to October next year. This will be the first major international exhibition since the war and the largest of its kind ever held—over 30 million visitors are expected, and it will occupy an area of 500 acres. On the British section, which will cover 5½ acres of undulating parkland, there will be two pavilions, one organized by the Government at a cost of over £500,000, and a larger one entirely the responsibility of British industry.

The central feature of the exhibition will be the Atomium, a gigantic model of a single body-centred iron crystal 200 billion times enlarged, composed of nine spheres, each 59ft in diameter. The spheres will be soundproof halls linked by escalators and travelling belts running in tubular interconnexions. In the lower ones there will be an exhibition of the peaceful applications of nuclear physics in which Britain, USA, USSR, Norway and Italy will be taking part.

FRANCE

Industrialists meet in Paris

Four hundred industrialists from eleven European countries and the US are to attend an OEEC conference on *Nuclear Energy for Management* in Paris from April 1–5.

Presiding at the first session will be France's High Commissioner for Atomic Energy, Francis Perrin. This will deal with fundamental problems and will be followed by sessions on economic, technical and industrial aspects, national and international programmes. Chairman of the industrial section is Arnold Lindley, GEC director and chief of the GEC Simon-Carves Group. Other British speakers will include: H. J. Dunster, Safety Branch, UKAEA; J. A. Jukes, economic adviser to the AEA; L. Rotherham, Head of R & D Branch, Risley; J. C. C. Stewart, Director of Technical Policy, UKAEA (IG); and Denis Taylor, NUCLEAR POWER's instrumentation editor who, as announced last month, is joining Plessey Nucleonics Ltd as Director and General Manager. Other distinguished speakers will include Bertrand Goldschmidt (France), Lew Kowarski (CERN), Pierre Taranger (France) and Alvin D. Weinberg (US).

GERMANY

British at Hanover

British nuclear energy will be prominently publicized at the German Industries Fair at Hanover (April 28-May 7). The UKAEA, in cooperation with the Nuclear Energy Trade Associations Conference, have a stand covering about 3,000 sq. ft on which will be shown how far Britain has come and where she is going. With the aid of photographs, drawings, models and description, visitors will be shown how the demand for power is growing in the UK, and how it will be met by nuclear energy during the next 20 years. Calder Hall will be explained in detail and for comparison there will be drawings and descriptions of the new CEA stations. There will also be samples of equipment used at Calder Hall—fuel elements, control rod actuators, heat exchanger tubing, examples of special concretes, electronic equipment. Research for later stages in the new power programme will also be illustrated.

A special brochure, *Britain Leads in the Atomic Age*, has been prepared and will be available in both English and German. In addition, two NETAC technical representatives, Martin Whitehouse and Robert Kahn will be available on the stand to answer questions.

On a separate stand, covering about 700 sq. ft, the Isotope Division of Harwell will be showing the latest British developments. These will include: liquid level measurement, thickness gauging, gamma radiography and the effects of irradiation on plastics, pharmaceuticals and foodstuffs. It is noteworthy that Great Britain is now the biggest exporter of isotopes in the world and in the last two years has supplied over 2,000 consignments to Germany.

Copies of NUCLEAR POWER will be displayed on the British stand.

NETHERLANDS

Het Atoom starts July 1

An international atomic energy exhibition, *Het Atoom*, will be held in Amsterdam from July 1 to September 16. Organized by the city of Amsterdam under the patronage of Prince Bernhard, a special building to house the exhibits has been erected at Schiphol airport.

Purpose of the show is to demonstrate to the public how atomic energy is being applied for peaceful purposes and all exhibits will be integrated into the general theme. So far, Britain, USA, France, Belgium, Canada, the Netherlands, Norway and Burma have announced their intention of taking part and it is possible the Soviet Union might also be there. The layout is planned to include an historical review and a feature of special interest will be the original Cockcroft and Walton apparatus which is to be lent by the Science Museum, London. This was used in 1932 to accomplish the first laboratory transmutation of elements—Li to He by alpha bombardment.

The UKAEA will be showing a large model of Calder Hall and also much of the material which will already have been seen at the Hanover fair. There will also be a model of the AMF-Mitchell boiling water reactor, an order for which has just been placed by Germany.

There is to be an actual reactor on view. This will be the AMF pool-type research reactor delivered for the Reactor Centrum Nederland, and its action will be shown by Pye underwater television. During the Exhibition a number of conferences will be held.

SOUTH AFRICA

Plowden in Union

UKAEA Chairman Sir Edwin Plowden arrived in South Africa last month for a visit as guest of the government. His purpose was to meet those concerned with atomic energy development, particularly with uranium mining. During his stay Sir Edwin is visiting some of the uranium mining installations.

AEA open mining office

The UKAEA will open an office at Dodoma, Tanganyika, this month. This will give technical advice to uranium prospectors working in East Africa, and it will include a laboratory equipped for sample assaying. The Authority have already established a similar office in Salisbury to serve the Federation of Rhodesia and Nyasaland. An intensive search for uranium ore is being planned this year for the area along the borders of N. Rhodesia adjoining the Belgian Congo and Angola. In S. Rhodesia chrome is reported to have been found in the Ngoma area of the Belingwe reserve, the deposits being said to cover nearly 15 square miles.

SWEDEN

The next ten years—Hinton

Britain's first-round power reactors will produce electricity at a unit cost of about 0·66d compared with 0·60d for conventional base-load stations commissioned about 1960. This was predicted by Sir Christopher Hinton, managing director of the UKAEA (IG) in his Axel Axson Johnson Lecture to the Royal Swedish Academy of Engineering Sciences in Stockholm on 15 March. By 1970, he declared, nuclear electricity would have dropped to 0·47d a unit compared with 0·67d for conventionally generated power; by 1990 he visualized nuclear power at 0·32d, at which time combustion stations would be costing 0·84d a unit.

The following is a predicted breakdown of costs from nuclear power stations: figures are in pence per kWh (sent out).

	1960	1970	1980	1990
Depreciation	·37	·30	·26	·22
Interest on fuel	·06	·04	·03	·02
Fuel replacement	·24	·13	·08	·06
Operation	·06	·05	·04	·03
TOTAL	·73	·52	·41	·33
Credit for Pu	·07	·05	·03	·01
NET	·66	·47	·38	·32

In arriving at these, Sir Christopher said he recognized that nuclear stations would not always be of the base-load type and he had allowed annual load factors of 80, 70, 65 and 60 per cent for the four years tabulated.

Although expensive beryllium canning and ceramic techniques would undoubtedly come in, the fuel charges would fall because of the greater burnups which would be obtained. The plutonium credit falls practically to vanishing point because breeder and other advanced reactors would have to produce power at the same cost as from the gas-cooled reactors. As the cost of power from these falls, the advanced reactors would demand cheaper plutonium in order to compete. Furthermore, extended burnups mean more of the higher Pu isotopes which lower its value as fuel.

Sir Christopher's lecture—*The Future for Nuclear Power*—dealt with the development of atomic energy in Great Britain and in particular with the philosophy underlying the choice of the gas-cooled reactor. He went on to indicate how, taking Calder Hall as a basis, very much advanced designs are already possible. As a canning material, he thought beryllium the most promising but said that to take full advantage of it, the fuel must be in a ceramic form. He did not, however, see beryllium cans coming in until about 1963 by which time he expected gas outlet temperatures of 425°C with cans at 500°C. By 1968, he thought these temperatures would be hoisted to 500° and 600°C respectively. This, however, would mean a new conception in fuel element design. On pressure vessel steels, he thought the conflict between low temperature notch ductility and creep strength would be solved by a low-alloy steel, but he considered the double-skinned shell with intercooling promising. In moving forward, said Sir Christopher, the most daring progress must be made under conditions of the most stringent conservatism. All other engineering technologies had advanced not on their successes but on their failures. These, however, could simply not be allowed to happen in atomic energy and this placed a quite unusual responsibility on those responsible.

The predictions made by Sir Christopher Hinton were emphasized to be only a first estimate of the shape of development and he said they would need most careful analysis by firms who are embarking on power plant construction. They ought to realize, he went on, that much of their power plant business will be swept into this new field by the late 1960's. By then probably three-quarters of the plant laid down would be nuclear; by 1970 it would be practically 100 per cent. Design technology is advancing so rapidly that manufacturing provision had to be laid down on the basis of forecasts; it cannot follow in the wake of technical developments.

UNITED STATES

British offer to US

What began to look like another US-UK misunderstanding sprang up last month when, during a meeting of the Joint Congressional Committee on Atomic Energy on March 5, vice-chairman Clinton D. Anderson (Democrat, N. Mex) roundly accused Britain of withholding technical data on Calder Hall and the CEA stations when 'we give them all American information on the design and operation of the *Nautilus*.' This brought a smart rejoinder from London in the shape of an AEA statement which asserted that Britain has as yet received no information on military reactors (including *Nautilus*) under the 1956 amendment to the 1955 military bilateral. The AEA also stated that a wide range of valuable information on a number of reactor types had already been exchanged under the bilaterals. With regard to Calder Hall, the AEA considered it had supplied all that was required under the agreements, but admitted this was not the entire story by adding that it had now offered the AEC detailed information on Calder in return for similar data on Shippingport. This offer is still under discussion at top level. Information on the commercial reactors is at present being collected for transmission to the USA under article 1-D.

Under the 1956 amendment to the military bilateral, there is no automatic exchange—only agreement that information 'shall be exchanged to the extent and to such means as may be agreed.' Discussions on exchange procedures are due to begin this month according to a House of Commons reply by Mr Galbraith, Civil Lord of the Admiralty.

Reactor runaway at Los Alamos

The AEC revealed last month that the core of an experimental reactor at Los Alamos 'exploded' during testing in February. Named GODIVA because it was an 'unclad' or 'stripped down' assembly, the core consisted of a 6½-in. diameter uranium 235 sphere made from six pieces in three sections suspended on a tripod. The bolts holding the sections together failed under the heat from a supercritical condition caused by a malfunction of special test equipment and pieces were scattered for several feet around the reactor room. An AEC statement said that no one was injured and no damage was done to the building housing the reactor, but the power unit was destroyed.

Radiation contamination has since been removed by standard cleaning methods. At the time of the explosion,

the reactor was being used as a neutron source for instantaneous irradiation of uranium-loaded graphite. The experiment was to determine the behaviour of this material after exposure to a sudden wave of neutrons.

From the information available it would seem that GODIVA was used for investigating transient conditions and it is therefore likely that its research function was of a military nature.

Bohr wins Atoms for Peace prize

The first *Atoms for Peace* award is to go to Prof Niels Bohr. This is the award set up in 1955 as a memorial to Henry and Edsel Ford, and carries an honorarium of $75,000. Born in 1885, Prof Bohr worked with Rutherford for several years at Manchester University, and has been professor of theoretical physics at Copenhagen University since 1916, winning the Nobel Prize for Physics in 1922. He left Nazi-occupied Denmark in 1943 and went to the US. The citation accompanying the award says 'known to his colleagues as a shy and humble man, unaware of the awe in which he is held by most scientists, Professor Bohr communicated to his fellows, and to students and scholars everywhere, a spirited sense of enquiry into new knowledge that is credited with having stimulated atomic research for peaceful purposes in laboratories throughout the world'.

Vance claims US leads

America should support to the best of her ability foreign nuclear power programmes by providing enriched fuel, chemical reprocessing at reasonable cost and a market for plutonium and other byproducts. This was stated by Atomic Energy Commissioner Harold S. Vance speaking during the 1957 Nuclear Congress in Philadelphia last month. Mr. Vance asserted that the United States was definitely ahead of the world in the technological development of atomic power and he was confident she would retain that lead. He said the object of the domestic programme was to find out the types of reactor capable of producing better-than-competitive power with the added characteristics of simplicity, reliability, safety and low capital cost.

The 1957 Nuclear Congress was held from March 11-15 and was sponsored by 20 engineering and technical societies representing over 300,000 members. The Congress actually consisted of four separate functions: *Second Nuclear Engineering and Science Conference, Third International Atomic Exposition, Fifth Hot Laboratories and Equipment Conference* and *Fifth Atomic Energy in Industry Conference*. Altogether about 150 papers were presented.

INTERNATIONAL

The Euratom 15000MW plan

The Euratom treaty was initialled in Rome on March 25 and is now awaiting ratification by the six contracting countries—France, W. Germany, Italy, Netherlands, Belgium and Luxemburg. The treaty, as finally drafted, contains six main headings: *Institutions, Supply, Ownership, Common Undertakings, Common Market* and *Security Supervision*. One member from each State will form the *Council* and the *Assembly* will consist of 142 members. The *Commission*, or executive body, will comprise five members and under it there will be a scientific or technical committee, a court of justice and an economic committee. A supply agency will be set up for processing and distributing fissionable materials to the member states. These materials will remain the property of Euratom. The treaty makes provision for common undertakings in which non-members of other international organizations will be allowed to participate. One year after the treaty is ratified all tariff and quantitative restrictions on export and import of minerals, fuels and other specified products will be abolished between the members. To ensure that materials are not put to uses which have not been declared by the user, a security system is planned, consisting of inspectors with rights of access to undertakings and a special method of accounting for minerals and fissionable material.

Earlier, the 'three wise men of Euratom' — Louis Armand (France), Franz Etzel (Germany) and Francesco Giordani (Italy) visited Great Britain for discussions with the authorities.

The Armand Committee's mandate when they set out, was to report on 'the amount of atomic energy that can be produced in the six countries in the near future and on the means whereby this can be achieved.' The answer to the first part seems to be about 15000MW by 1967, but as to the best way of achieving this they were silent. At their Press conference in London on March 1, Prof Giordani and Herr Etzel (M. Armand had had to return to Paris urgently) stated they had been very impressed by Calder Hall and by the British approach to power programmes in general but they were not prepared to divulge at that stage what their final recommendations on suitable reactor types would be.

The Euratom plan of 15000MW by 1967, it will be noted, is about twice the size of Britain's new Mills plan and considering the present state of atomic energy in most of the six countries it is not easy to see how this can be carried out in the time specified, although it is considered 'feasible' in the US. Clearly, Euratom's first power plants will have to come from America or Britain and there is bound to be determined competition for these large contracts. There is reason to believe that the Armand Committee are more inclined to the British system than to the American but the fact that the AEC have promised supplies of enriched uranium must weigh heavily. At the London Press conference Franz Etzel expressed the hope that Britain would associate herself with Euratom exactly as with the Common Market plan but he felt bound to add that if there were not cooperation 'Britain's position would not be so favourable.'

That cooperation has been given by Britain was, however, admitted when it was announced that a 'task force' of experts had been lent by the AEA to Euratom to assist in its technical considerations. The names of the British team were not, however, disclosed. In addition, the AEA are to provide contacts with UK firms and places at the Harwell Reactor School and the Calder Reactor Operation School.

The 'wise men' of Euratom seen in London recently with AEA chairman Sir Edwin Plowden—(l to r) Louis Armand, Sir Edwin, Franz Etzel, Francesco Giordani

Frogmen wearing disposable plastic overalls over their rubber suits dismantle the collector unit. Beyond sits the controller outside the sealed space

As burnups in power reactors pass 1000 MWD/t plutonium isotopes above 239 accumulate. To fix cross-sections, milligram quantities of the pure nuclides are required

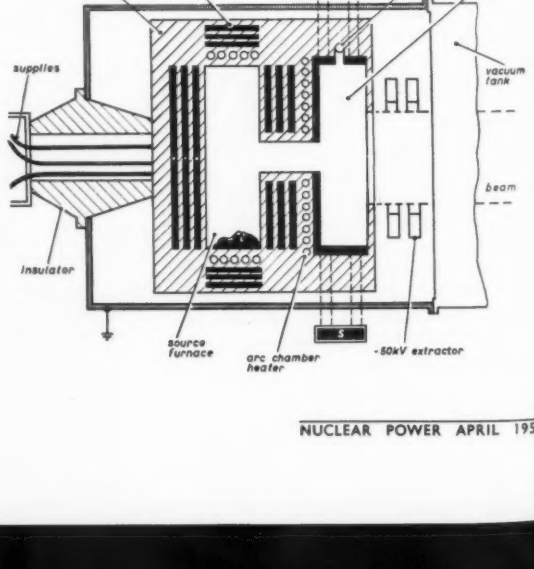
Electromagnetic separation by HERMES

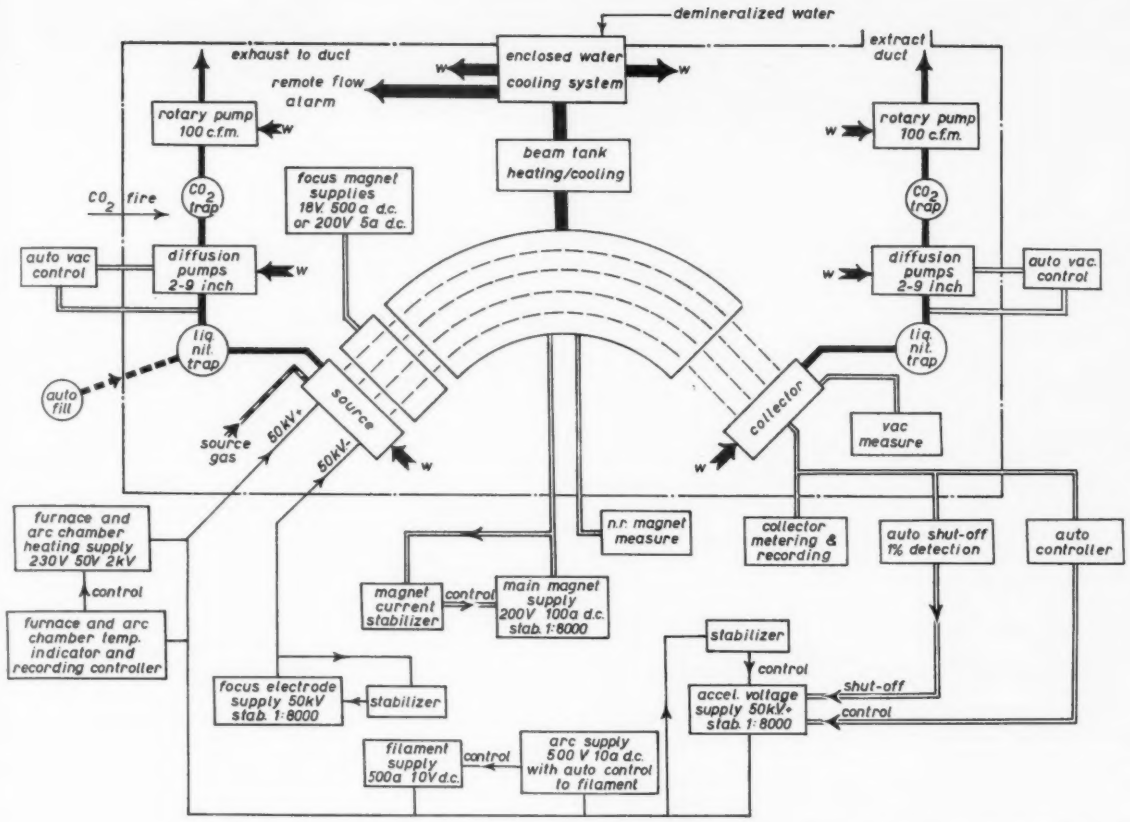
THE LARGEST AND MOST COMPLEX apparatus to be built completely inside a dry box at Harwell is now in operation. This is the isotope separator known as HERMES, from its full name—Heavy Element Radioactive Material Electromagnetic Separator. In principle this is a mass spectrograph. Positively charged ions travelling at constant high velocity enter the field of an electromagnet where they are deflected from their straight path into an arc of a circle whose radius depends on the mass of the particle. When the source consists of a mixture of isotopes, these travel in slightly different trajectories to separate focuses and, with the use of a suitable collector, the isotopes may thus be isolated. The apparatus is versatile and could be used for any element, but at present it is being used to separate and collect in milligram range quantities the four plutonium isotopes 239-242 in order to investigate their fission and absorption cross sections. With a modified source which will be ready in a few months, known as the economy ion source, the apparatus will handle beta- and gamma-active fission products up to the 1 curie level. This is of novel design based on Scandinavian work and employs end extraction from the arc chamber in contrast to the side extraction of the universal ion source used for the transuranic elements. For preliminary studies of the behaviour of the apparatus, particularly the transmission of the ions through the tank, the source material may be injected in gaseous form.

The universal source at present in use is in two sections and measures approx 9in. cube. Solid plutonium trichloride —about 10g—is vaporized at 900°C in the electric furnace which is kept at a constant temperature of 1000°C, and passes into the arc chamber. This is also heated to 1000°C by the same supply to prevent condensation of the plutonium vapour. Temperature control is achieved by slave indication and recording instrumentation.

In the arc chamber the vapour is ionized by electron

For transuranic separations the universal ion source is used. Vertical section shows electric furnace, arc chamber and accelerating electrodes





Block schematic of whole plant shows services in the sealed space and connexions to the adjacent control room

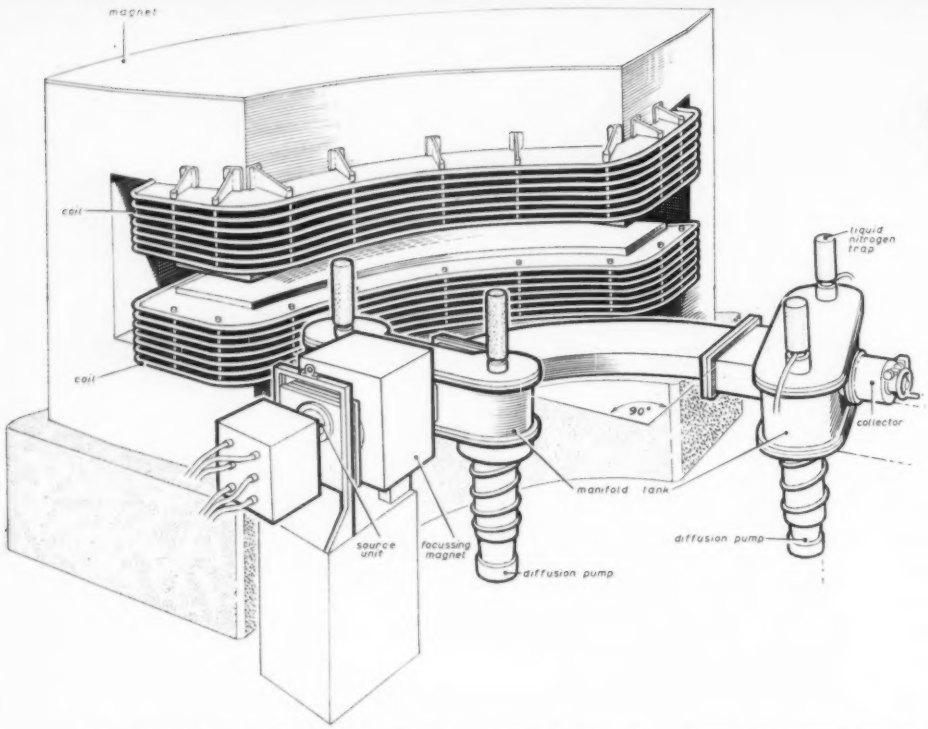
bombardment at one micron pressure. The electron source is a tantalum filament mounted on insulated legs and heated to 2500°C. Positive plutonium ions are collimated into a vertical plane by a magnetic field of up to 1000 gauss, aided by a charged focus plate, and the beam is extracted from the chamber by a slit electrode which can be charged to 50kV negative. The ground electrode is chargeable to 50kV positive giving a total possible accelerating potential of 100kV, the value normally used being about 55kV. The high voltage supply is stabilized to 1 in 8000.

The ions pass through the graphite beam slit (2mm by 23mm) into the manifold vacuum tank within the electromagnet where the pressure is 2×10^{-5} mm Hg. The tank is of stainless steel and was made to a special design requiring X-ray testing of the materials before and after fabrication and a full leak-test. Rectangular in cross section, measuring 6in. by 2½in., it covers a 90° arc of 4ft radius. The electromagnet produces an infinitely variable field with a 4000 gauss maximum stabilized to 1 in 8000 by negative feedback. The magnet is mounted on a massive concrete foundation and the beam tank fits between the pole pieces. The coils are supplied with demineralized water cooled in an air blast heat exchanger located outside the building. This system also cools the source, collector and vacuum pumps. At its normal field strength of 4000 gauss, the magnet takes 100V, 20 amps and the design is such that the field strength is substantially uniform over the whole ion path. Final separation of the Pu isotopes is only about 0·2in. making accurate stabilization of both the accelerating and deflecting fields essential.

The separated isotopes collect as the metal in the evacuated copper collector unit, which is divided into four compartments. Ions enter the collector through four parallel slits and pass into the appropriate section where they intercollide, gradually losing their charge, and finally penetrate the copper to a depth of about 50 atom planes and alloy with it. The collector unit is water-cooled, the heat to be removed being equivalent to about 40 watts. When enough plutonium has been collected the box is dismantled and the plutonium-containing copper dissolved in acid. The isotope is then separated from the aqueous solution, the whole operation being of course performed in a glove box. The usual period of operation is two or three days and nights and the yield is 4 per cent. Half the remainder is recovered from the source unit after each run, and the rest accumulates through the machine and is recovered when major cleaning is done. For this a special vacuum cleaner is fitted to the suction side, and special scraping and brushing tools are used.

The pumping system comprises two refrigerated 9in. oil diffusion pumps backed by an eccentric vane rotary pump which gets down to 100 microns. The trap between them, to condense out any water in the system, is filled with butylcellosolve. It is fed through closed circuit coils from a heat exchange tank outside the dry box kept filled with a CO_2-butylcellosolve sludge. The liquid nitrogen trap assists the pumping of the vapours and also holds back the diffusion pump oil.

The risk of shorting or motors seizing within the dry



Exploded view of magnet shows four-foot-radius 90-degree ion path in stainless steel vacuum tank

box constitutes a fire hazard. There is also a danger of local sparking when the source is 'pulled' after a run due to the pyrophoricity of finely powdered metallic plutonium which collects in the arc chamber. As the operators can remain in the box only for a limited period, special fire precautions have been taken. A pipe-line distribution system, fed by a battery of five carbon dioxide cylinders, terminates in a number of discharge nozzles, distributed through the protected space, which can supply sufficient gas concentration to render the atmosphere inert. The system can be operated at the gas cylinders or at the control desk.

The dry box measures approximately 25ft by 21ft by 14ft, a plate glass window separating it from the control room. It can be entered only from the frogman maintenance area by personnel in rubber frog suits who are in telephonic communication with the control desk. The continual observation necessary to keep the ion beams in precise focus is achieved by closed circuit television, of which the camera is specially fitted with a shield so that it can operate in the strong magnetic field. It can also be used by the frogmen to show assembly details to the operator at the control desk. 1500 automatic circuits link the controls with the sealed space.

Control of HERMES is carried out from a 3-section console outside the dry box from whence the scientist in charge can see the whole apparatus. The left hand panel houses instruments at 50kV potential, all controls to this unit being insulated on extension rods. To provide ready access to the electric supplies, this unit is hinged and in the closed position catell locks ensure complete safety.

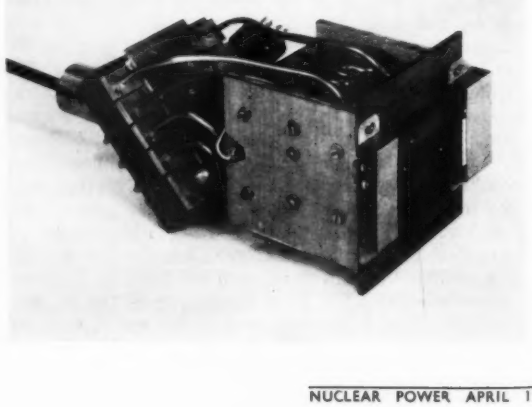
An interesting engineering problem was furnace temperature control. An electronic potentiometer with a three-term pneumatic control, housed in the high tension supply cage, is connected to a miniature pneumatic recorder in the control desk by a polythene air line. This insulates the operator from the h.t. supply.

Instantaneous disconnexion without leakage of the cooling water pipe-line posed another problem. Special self-sealing couplings are used each half of which contains a spring-loaded valve which, on disconnexion, automatically closes the portion of the pipe to which it is attached.

Among the contractors who supplied components or services were :

W. E. CHIVERS & SONS LTD	*building*
MATTHEW HALL & CO LTD	*erection of water cooling plant*
ENGLISH STEEL CORPORATION LTD	*magnet*
LONDON TRANSFORMER PRODUCTS LTD	*magnet coils*
WESTERN DETAIL MANUFACTURERS LTD	*manifold vacuum tank*
PRESSED STEEL CO LTD	*refrigeration plant*
A. & E. LINTOTT LTD	*control desk*
THE PYRENE CO LTD	*CO_2 fire extinguishing plant*
THE POWER CENTRE CO LTD	*trunking*
PILKINGTON BROS LTD	*plate glass for dry box*
PYE LTD	*closed circuit television*
ERNEST TURNER & CO (SALFORD) LTD	*metering instruments*
EDISON SWAN ELECTRIC CO LTD	*triode regulators*
STANDARD TELEPHONES & CABLES LTD	*diode monitors and rectifier valves*
LOCKHEED HYDRAULIC BRAKE CO LTD	*Lockheed-Avery couplings*
HONEYWELL-BROWN LTD	*ElectroniK strip chart recorders and teleprinter controllers*
FIELDEN ELECTRONICS LTD	*servograph chart recorders*
STEATITE AND PORCELAIN PRODUCTS LTD	*special insulators*

Collector unit seen here has back removed to show water cooling pipes leading to each of the four compartments. When mounted, slits are vertical



A résumé of current practice and future trends in design and manufacture of the electronic type of transformer with special reference to atomic energy applications

TRANSFORMERS IN NUCLEAR INSTRUMENTATION

T. P. LYNOTT, AMIEE

Gardners Radio Ltd. Until recently, Head of Transformer Section, Electronics Division, AERE, Harwell

UP TO THE BEGINNING of the second world war, small transformers of the type used in electronic equipment received little attention. Items for Service use were usually made reliable by the application of large safety factors which made them heavy and bulky; it was also almost universal to give some tropical protection by means of a bitumen sealing coat.

Large numbers of transformers were used without impregnation. With increasing demands both for quantities and greater reliability particularly in the Radar field it became obvious that development work was needed and much of the early development[1] was carried out by the Admiralty and later in conjunction with RCSC[2] and RCRDC[3] (the Interservice Standardization and Development Committees) and with the cooperation of industry the present design of hermetically sealed and open type 'C' core transformers were developed.

Grain-oriented cores

One of the most outstanding advances in the transformer field has been the introduction of grain-oriented cold rolled silicon iron which is most efficiently used (in small transformers) in the form of the now well known 'C' core. This type of core is manufactured from grain-oriented silicon iron having a low silicon content, the material being produced in strip form, insulated on both sides, and wound into a rectangular form having a suitable build up. After annealing, the core is impregnated to ensure that the laminations are bonded together, and then cut, usually centrally, across the face. The cut faces are etched to remove burrs formed in cutting and to prevent the laminations shorting at the edges. The two halves are always kept together as a pair and are usually referred to as a loop, two loops normally being used to form a complete core.

This form of construction enables the core flux to follow the direction of grain orientation and enables cores to be operated at up to 30% higher flux density than with normal silicon iron. Maximum flux density at which cores are normally operated is 17000 gauss, but with good cores 18000 gauss is a permissible maximum if a relatively high magnetizing current can be tolerated. It is, however, advisable with cores above the 50/32 size, to operate at slightly lower flux densities since due to the high permeability of this type of core switching surges are much greater and difficulty with fusing has been experienced with the larger cores. The external field is less with the 'C' type core.

Standard assemblies

Standard assemblies for both sealed and open types have been developed and are covered by the RCSC lists RCL 215 and RCL 216 respectively. Certain of these assemblies are also suitable for use with laminations.

Reliability

The hermetically-sealed oil-filled transformer designed to RCSC standards has proved to be a thoroughly reliable component when correctly manufactured, processed and installed and used under the conditions for which it was designed.

The Atomic Energy Research Establishment has used 'C' cores and the standard assemblies since their introduction and has had nearly eight years' experience in the design and manufacture of transformers incorporating them both for prototype and small quantity production. In nuclear instrumentation and reactor control it is necessary in many instances for transformers to be called upon to operate continuously for long periods and breakdown may be serious. This is one of the reasons why the sealed transformer has been used, and although the open type is now used as first choice on the question of cost the sealed type is still preferred where the highest degree of reliability is required.

By careful examination of equipment requirements, cooperation with the equipment designers and a close control on specifications together with the use of approved sources of supply it is possible considerably to increase reliability; fault records show a drop by a factor of 4 times in failure rates for transformers—once the most unreliable of components.

Where an equipment is sealed, it may be considered sufficient to call for a transformer of cheaper construction and finish, but any saving in first cost may be nullified by the increased cost of packing since a large number of failures of open type transformers is due to deterioration in storage since the open type transformer (even when correctly impregnated) is a moisture sensitive component

CET ARTICLE donne l'aperçu des techniques et tendances actuelles en Angleterre en ce qui concerne la construction et fabrication des transformateurs électroniques, et spécialement leur emploi dans l'instrumentation des dispositifs nucléaires. Un progrès saillant achevé au cours de quelques années dernières, c'est l'introduction des noyaux en acier au silicium, laminé à froid et ayant des grains orientés. Néanmoins la demande croissante des types de petit format conduit à l'emploi de plus en plus croissant du ferrite et nickel-fer. Parmi d'autres développements on peut citer l'emploi des liquides de remplissage non inflammables et de l'isolation en résine fondue. On a employé la radiographie gamma comme un moyen utile du contrôle des défauts intérieurs.

DIESER AUFSATZ stellt eine Zusammenfassung der gegenwärtigen Verhältnisse und Tendenzen dar, betreffend Konstruktion und Herstellung elektronischer Transformatoren in Grossbritannien, unter besonderer Berücksichtigung ihrer Verwendung in der Nuklearinstrumentation. Einer der bedeutendsten Fortschritte, die während der letzten Jahre gemacht wurde, ist die Einführung kaltgewalzter Siliziumstahlkernstücke mit orientierten Körnern. Der wachsende Bedarf nach Miniaturtypen hat jedoch eine grössere Anwendung von Ferrit und Nickeleisen zur Folge. Andere Vervollkommnungen umfassen die Anwendung von nicht entflammbaren Füllflüssigkeiten und Gussharzisolation. Gamma-Radiographie wird als nützliches Kontrollmittel bei Innenfehlerprüfung angewandt.

EL ARTICULO facilita un resumen de los procedimientos y tendencias inglesas en el diseño y fabricación de transformadores electónicos, con especial referencia a su empleo en instrumentos nucleares. Un notable adelanto en los últimos años ha sido la adopción de núcleos de acero al silicio laminado en frio y de textura orientada. Sin embargo, la demanda cada dia mayor de tipos miniatura ha dado lugar al creciente uso de ferrita y hierro-niquel. Entre otras evoluciones figuran el empleo de flúidos de relleno no inflamables y de aislación de resina moldeada. La radiografía gamma ha sido utilizada como un medio útil de inspección para comprobar las fallas interiores.

ЭТА СТАТЬЯ является резюме нынешней английской технологической практики и существующих тенденций в проектировке и продукции электронных трансформаторов, в особенности относительно их использования в ядерной инструментации. В течение нескольких последних лет выдающимся успехом было изготовление активных зон из кремниевой стали холодной прокатки с ориентированными зернами. Однако возрастающий запрос на миниатюрные типы ведет к большему употреблению феррита и сплава никкель-железо. В числе других усовершенствований следует отметить употребление невоспламеняющихся жидкостей наполнения и изоляции из литых искусственных смол. Гамма-радиография употребляется как полезное средство проверки при контроле внутренних дефектов.

and may well absorb sufficient moisture (if inadequately processed) in storage to cause breakdown when put into service. There is no great difficulty in producing a reliable open type transformer to meet H2 conditions providing care is taken in manufacture and the coil is adequately processed.

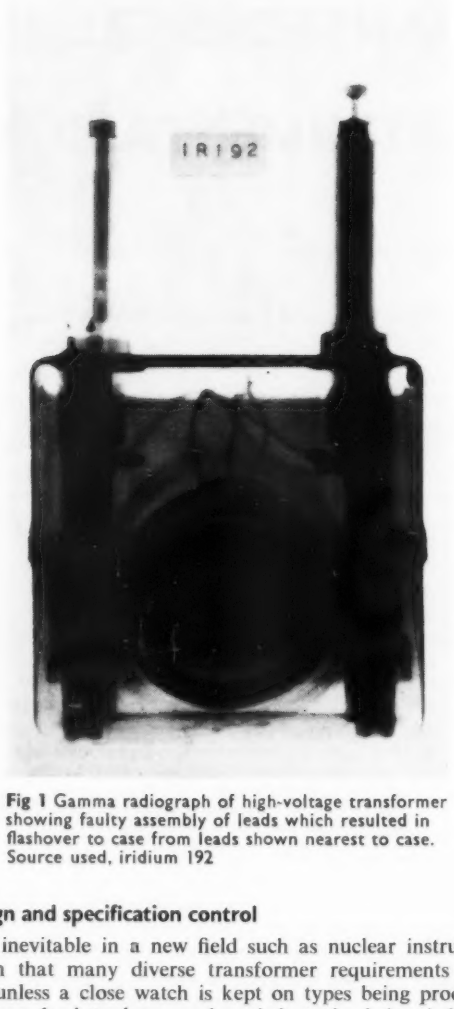


Fig 1 Gamma radiograph of high-voltage transformer showing faulty assembly of leads which resulted in flashover to case from leads shown nearest to case. Source used, iridium 192

Design and specification control

It is inevitable in a new field such as nuclear instrumentation that many diverse transformer requirements arise and unless a close watch is kept on types being produced this can lead to large and varied stocks being held for spares and general consumption.

However, with cooperation between transformer design staff, equipment designer and equipment manufacturer—and it is appropriate to record that, in the writer's experience, this is willingly given in most cases—it is possible to reduce considerably the types of transformer held in stock.

A design memorandum has been produced which lists all approved transformers and chokes in use in equipments, including items having standard ratings, and it also outlines requirements and gives guidance on the selection of transformers and chokes. Dimensions and standard chassis cut-outs are also included. The designer can select a suitable type from this list and its suitability is subsequently checked by the design office to ensure that it is being used within its rating. If it is found that a particular transformer is suitable except for the need of an addi-

tional tapping or perhaps slight uprating, then it is very often possible to modify its specification, and thus make one component serve two equipments.

Ranges of transformers having standard ratings are carried and industry has cooperated very fully by having these available with reasonable deliveries; as these can be made in larger quantities they are of course cheaper than the individually designed component.

Standard assemblies can nearly always be used in AERE equipment and minimum space requirements have been laid down for all standard assemblies; thus with the use of standard cut-outs and terminal positions open and sealed transformers are directly interchangeable.

Transformer requirements

The power transformers used in nucleonic instruments range from 5 or 10VA to 750VA and voltages up to 1kV or in some cases up to 5kV. There are limited requirements up to 10kV d.c. working. Above 1kV, oil-filled components are used. Reactor control equipment may use transformers considerably larger than 750VA.

In the past, the majority of equipments have used valve rectifiers in bi-phase half-wave circuits, but increasing use is now being made of metal rectifiers most efficiently used in the bridge circuit.

In addition to power transformers using standard assemblies, there are many different types used such as RFEHT units which have been manufactured using ferrite cores together with rectifiers and associated condensers all contained in a standard can assembly. There are many requirements for small pulse transformers, matching transformers and a very rapidly expanding use of miniature and so-called sub-miniature transformers for use in transistor circuits.

A component closely allied to transformers is the transductor and although few have been used so far in nuclear instrumentation they are, as part of magnetic amplifiers, being used in reactor control circuits.

transformers using these cores have formed the bulk of the requirements to date. The increasing demands for miniature types, however, means that more ferrite and nickel-iron cores are being used.

More efficient designs could be produced if nickel-iron materials were available having higher guaranteed permeability, since at present wide variations can occur in stocks of laminations. Vibrator transformers have used 50% nickel-iron due to the requirements for low battery drain but grain-oriented laminations have given comparable results. Small ring-type ferrite cores are used in large numbers for computers and ferrite cores are also being used for transistor oscillator power supplies [7, 8, 9].

In the past two or three years, the resin cast transformer has been developed; although these have not been used by AERE for power transformers they may well prove competitive to oil-filled components both in price and reliability. They also avoid the possibility of oil leakage, but until their long-term reliability is established it is unlikely that they will altogether replace the sealed type. One important point which should receive consideration is the fire hazard; certain modified resins may be a greater fire hazard than the sealed component.

New Filling fluids

There is likely to be a move towards the use of non-inflammable filling mediums for some applications. The Askarel group of fluids appear to be most promising for this purpose, but although they have been widely used in large power transformers, as far as the writer is aware they have not been used in the smaller type of transformer. One difficulty is that some of the commonly used transformer materials are attacked by these fluids, and therefore changes in design would be needed; also, of course, separate impregnating plant would need to be used since these fluids cannot be mixed with transformer oil. It is not considered however, that these are difficulties which cannot be fairly readily overcome and it may well

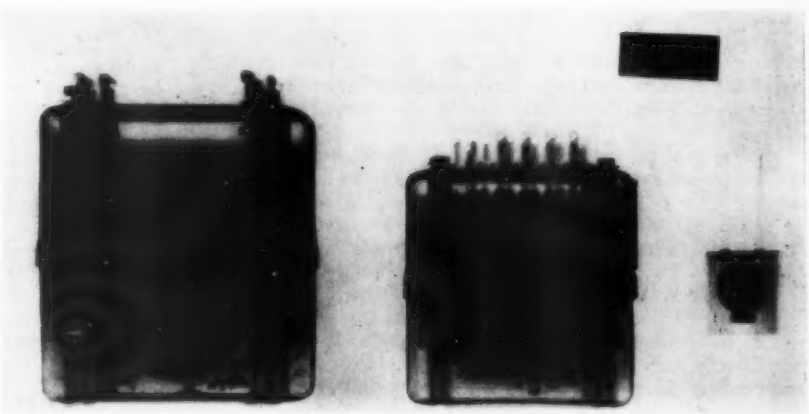


Fig 2 Further examples of gamma radiographs of two oil-filled and one resin-cast component, the latter using a mica-filled resin. The larger component clearly shows a rather poor shape coil and lead connexions very near the can base

Vibrator transformers have been used in relatively large numbers but the increasing use of transistors may well reduce the quantity of these, it has always been a problem to produce reliable low power vibrator transformers[6].

Core materials

Grain-oriented cores have already been dealt with and

be that future requirements will call for this type of filling medium; in the meantime prototype transformers are being designed and made so that comparative testing can take place.

It is possible that transformers, particularly of the smaller types, may need to be made in cylindrical form, since this is most convenient where automatic production techniques

are involved in the production of electronic equipments or assemblies.

Improved core materials may lead to a greater use of tape-wound cores particularly for transistor circuits, and a recent development in the form of the shell core[10] shows promise for further reduction in the size of miniature transformers. Transformers operating up to 150°C are being increasingly used, but will probably not be necessary in the nuclear instrumentation field except where operation in aircraft is required.

It may be worthwhile considering the use of gamma radiography for the examination of transformers; this can be useful where it is desired to examine a faulty component before it is opened up. Figure 1 shows an oil-filled component which developed a fault; the radiograph clearly shows up an example of bad assembly—several of the high voltage leads have been left slack and one has shorted to the case. It is suggested that in the case of resin-cast transformers, radiographs should be taken as a check on casting quality.

Future Requirements

This article has so far detailed methods used by AERE and has reviewed what has been done in the past. Although the transformer position is much better than four or five years ago from the reliability angle there is still room for improvement in many directions. Core materials and the need for better quality have been mentioned. Greater care is needed in many cases in the positioning of transformers: adequate space should be allowed and the practice of fitting transformers in a prototype with the cases touching is bad. It makes no allowance for tolerance on the size of can—the maximum specified dimensions should always be used.

Where possible, if space permits it is better to use separate transformers for h.t. and heater supplies since this simplifies fusing.

Good regulation of heater transformer output voltages is desirable since this means that one transformer can be used in various requirements having different current requirements.

Greater care is necessary in correctly rating transformers. Many instances still occur where the final demand on the transformer is much higher than estimated and it is often difficult to incorporate a large core size. Series-parallel connexion of primaries is preferable where 110V operation is required in addition to the normal input voltages.

Transformer requirements should be considered early in the design stages and every endeavour made to use standard types or types which are already in use. In designing or producing prototypes it is important to remember that these may have to be produced in quantity and that 'laboratory results' may not be reproduced without selection of cores and wire; cores—particularly nickel-iron—may vary within wide limits and resistance of winding wires—particularly fine gauges—is also subject to wide variations. Adequate test data should be given to enable components to be correctly made and inspected; this applies particularly to pulse, matching or input and output transformers. Where it is considered desirable to use resin-cast components it must be remembered that the component should be designed for casting. Cast components although taken through a full curing process may still show up changes of inductance after several weeks. When using nickel-iron or ferrite cores, the design should be such that a gap can be incorporated otherwise it is almost impossible to guarantee stable components.

One final point concerns the ordering of transformers. The transformer manufacturer can only provide a correctly designed component if he is given full information as to requirements. Too often, only brief details are given, particularly of rectifier circuits: It is necessary to give full details of rectifier type, type of circuit (including smoothing) and any unusual voltage working conditions.

Standard component parts

It is very necessary to use standard assemblies, cores etc., whenever possible. Preferred sizes of laminations for small transformers are RCSC numbers 450, 421, 439 (or 458) MEA 176 (Scott 312). Ferrite cores are available which correspond to these sizes and also moulded bobbins so that the same bobbin, frames and cases may be used for both types of core. It is hoped that some standardization of lamination sizes below the 176 will be made as the use of smaller laminations is increasing rapidly.

Summary of future requirements

The future requirements for nuclear instrumentation can be summarized as follows:

1. Greater reliability by increasing use of approved components
2. Reduction of fire hazard
3. Greater use of standard components
4. More care in selection and installation
5. Adequate testing of all transformers before incorporation in equipments
6. Reliable components at reasonable cost
7. When an equipment is to be produced both for a commercial market and to meet Service requirements then the design should be such that the approved component can be used and readily replaced for commercial models by a cheaper form of construction having possibly a higher temperature rise. One manufacturer is already producing transformers directly replaceable with standard 'C' core assemblies.

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NUCLEAR POWER VOL I No 1

We have had a number of requests for copies of our first issue (May 1956). Unfortunately this is out of print, but it may be consulted in various libraries, including the British Museum, Science Museum Library and Patent Office Library. The latter two also have a photocopying service, and photostat copies of particular articles may be obtained through these at the following addresses:

Science Museum Library, South Kensington, London, SW7

Patent Office Library, Southampton Buildings, Chancery Lane, London, WC2

Experts from 13 nations met recently at Harwell to discuss problems of handling radioactive and toxic materials.
A NUCLEAR POWER special correspondent reports

Glove Box design and operation

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AN INTERNATIONAL SYMPOSIUM on *Glove Box Design and Operation*, sponsored by the United Kingdom Atomic Energy Authority, was held at Harwell from February 19 to 21. Two hundred and fifty delegates from the UKAEA, the industrial firms involved in the UK nuclear power project, and from Belgium, Canada, Denmark, France, Germany, India, Italy, the Netherlands, Norway, Portugal, Spain and the USA attended.

Papers were presented under the general headings: Safety Aspects; General Design; Installations and Maintenance; Applications, with a further sub-division into shielded and unshielded installations.

The health physics aspect of glove box design and operation were introduced by H. J. Dunster and E. J. Bennellick (Harwell). Experience has established the toxicity of all radioactive materials and the need for special handling techniques to minimize inhalation and ingestion and keep exposure to external radiation down to a safe level. Practices at different laboratories are basically similar.

Handling is carried out either in fume hoods or an enclosure maintained at about −1 in. static water gauge pressure relative to atmosphere, so that leakage is not into the laboratory. Once active, a box is maintained at a negative pressure continuously by being connected to a suitably filtered extract. Most laboratories recommended particulate filters of pleated glass fibre. Access to equipment is generally through ports on the sides of the boxes, into which long sleeved rubber gloves are sealed. Where a toxic dust hazard is involved, an inert atmosphere, usually high purity argon or helium, is preferable.

Boxes must be decontaminable

The papers on general design emphasized that ease of decontamination is an important factor in the choice of structural materials. In general practice, a mild steel shell coated with either strippable or fixed paint is used. The former aids decontamination but ages, becoming brittle and cannot be applied where heavy handling is envisaged. Epicote fixed coat paints, resistant to solvents, HNO_3 and HCl are widely employed. The high corrosion resistance of stainless steel in many cases justifies its high initial cost, and such boxes have been in operation at Los Alamos for many years. In these, lead backed zinc chromate tape has been used for smoothing the interior contours to facilitate decontamination.

Because it is easily machined and readily available, Perspex has been generally used for working faces. Where fire risks are involved a higher melting point chlorinated Perspex, or a rigid p.v.c. were suggested, though the amber colour of the latter reduces visibility. In these circumstances safety glass windows are favoured at Los Alamos.

Tests on a wide range of suitable glove materials were reported from the Atomic Weapons Research Establishment, Aldermaston. The most suitable appears to be neoprene. Though of relatively low tear strength, it is more resistant to oil than natural rubber, less permeable to gases and longer-lived under the action of heat, oxygen and ozone. Though there was general agreement on this point, a life of as long as four years—reported by F. W. Schonfeld for some neoprene gloves at Los Alamos—provoked some comment from British delegates, where experience with neoprene has been variable. It was suggested that the instability of the latex suspension, which has to be transported from America, and which has led to production difficulties in the UK, may have been a contributory factor to the relatively rapid deterioration observed in some cases. It was also felt that the long-term build-up of surface contamination on gloves in use for long periods could constitute a serious health hazard where beta or gamma sources, or impurities are present.

Of the decontaminating methods discussed, most interest lay in the vapour blast technique, in which heated decontaminating solution with a suspension of mild abrasive or adsorptive earth is directed at high pressure onto the contaminated surface. It has proved most efficient on small articles.

HERMES described

Atomic Energy Authority, French and American delegates described plutonium handling facilities for such varying operations as separation and reduction, chemical engineering, dryway fluorination and hydrofluorination and metallurgical fabrication and research. The Harwell electromagnetic isotope separator (J. H. Freeman and M. L. Smith) was of particular interest as the largest and most complicated glove box installation described.*

Whilst most of the work reported dealt with the handling of plutonium, or U-233, several papers covered other specific topics. In one of these, K. W. Bagnall (Harwell) described the preparation of chemical compounds from milligram quantities of polonium 210 (Specific activity 4·5 curies/mg). The difficulties of control with this isotope—previously attributed to an aggregate recoil mechanism—are apparently due to volatile compound formation.

Both in the papers on unshielded installations and in the vigorous discussions which followed three points stand out. These are: the differences between the British and American approach to the question of total containment; the problem of production and the necessity for high purity inert atmospheres; and the need for both fully engineered and prefabricated boxes.

The view of the UKAEA health physicists on the question of toxic hazard has been that the maximum permitted air tolerance levels recommended by the International Commission on Radiological Protection, should never be exceeded, even during maintenance. Their experience in handling plutonium led H. J. Dunster to suggest that complete box integrity becomes necessary for activity levels equivalent to 1-10 millicuries of plutonium (10-100 mg) in wet chemical operations, or 10-100 microcuries of plutonium (0·1-1 mg) in dry operations where the formation of

* A description of this plant appears on p 132

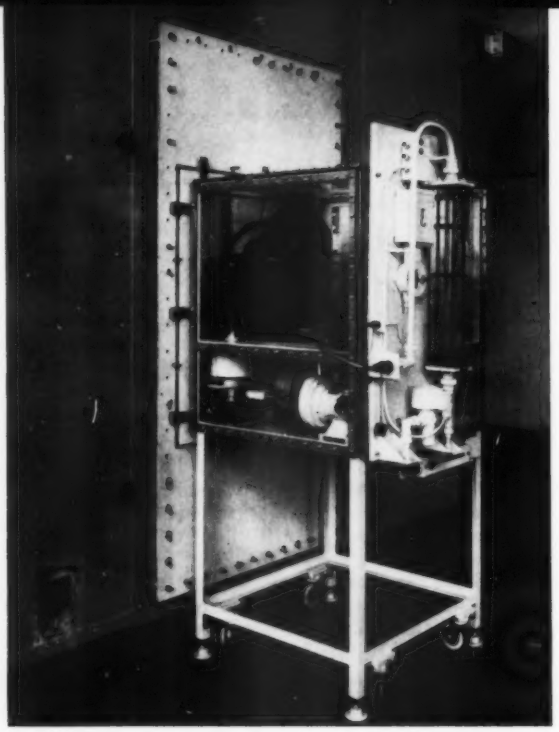


Fig 1 A free-standing glove box attached to a frog suit facility

fine dust increases the hazard. Equivalent figures for other isotopes can be obtained by direct comparison of air tolerance levels. These values were generally accepted as reasonable, the need for close control being further emphasized by the fact that contamination introduced into the body via cuts is as serious a problem as ingestion. F. W. Schonfeld reported American experiments on animals as indicating that 20 mg of plutonium introduced via a cut will give 50% fatalities within 30 days ; 100 micrograms, 50% fatalities within 2 years.

Within the UKAEA, complete box integrity during use has been achieved with the adoption of the heat sealed p.v.c. bag transfer technique and the use of double grooved ports to facilitate glove and transfer bag changing. Although the trend has been away from fixed and island cell facilities directly connected with a frogmen maintenance area, to the more flexible single-skinned free-standing box developed by the Harwell Metallurgy Division, the latter are designed with one face developed to clamp against an adaptor plate on the wall of a frogman area to form a sealed surface. Access to this face is then possible via an air lock so that the face can be removed and the box itself becomes in effect an extension of the frog suit area and its interior accessible for maintenance (Fig. 1).

American maintenance practice has been to decontaminate the interior of the box in situ to as low a level as possible, and then to open up in the laboratory area. No frogman facilities are used but respirators and protective clothing are worn. At Los Alamos it has also been found possible to carry out microscopic examination and indentation hardness tests on plutonium in laboratory fume hoods, provided that the specimen has been freed from loose surface contamination before being passed out into the open laboratory. Boxes are coupled to form an activity gradient in the line, the specimen receiving its final decontamination in a low activity cell.

It was suggested that a contributing factor to the success of this system, which is in contradiction to British experience, is the low relative humidity (oxidation of plutonium in the presence of moisture produces a non-adherent oxide coat). Fifty per cent humidity has only a small effect. Regular decontamination of the inside of the box to keep the level of loose activity as low as possible would also appear a generally desirable practice. The use of personnel with a high sense of responsibility is imperative.

The question of box integrity was also implicit in the discussion on vacuum system practice. Within the UKAEA, the complete pumping system has generally been incorporated into the glove box proper or into a coupled box, the pumping tables being standardized for easy replacement. American practice has been to keep the pumping equipment readily accessible outside the box. Both, however, report that internal contamination is mainly confined to the oil diffusion pump which forms a very effective trap. It was suggested that box integrity would be maintained if the diffusion pump only is incorporated into the box, using it as a filter for the pumping system, with the proviso that some safety device be incorporated to prevent the box itself being pumped down in the event of a vacuum failure inside the box. This could be efficiently done by passing the backing pump exhaust back into the box. For small experimental vacuum systems, whose constituent parts are readily passed in and out of a box installation, inside the box is probably as flexible and where the atmosphere is an inert gas, the ' effective vacuum ' (i.e. judged by oxygen concentration), is enhanced by the box atmosphere.

Coupled with the question of box integrity is the question of box tightness. Rigid specifications have been laid down by most establishments requiring a leak rate of about 0·5% box volume per hour, or lower, at −1 in. static water gauge. It was clear from the discussion that this specification has largely been the result of a demand for high purity inert gas atmospheres. Whilst these appear necessary for work at elevated temperatures on plutonium, even where the operation is carried out under vacuum, they are not required for some work and a less rigid specification might be accepted except where pressurization of a box is possible. If a through draught is necessary, as in chemical work involving a corrosive atmosphere, it is preferably obtained from a controlled leak. The main source of trouble in achieving box tightness seemed to be the window seating. Here a neoprene seating, virtually an O ring retained by an attached fillet to the clamping bolts, seems a most promising development.

Several papers dealt with the problem of large scale high purity argon production but most discussion centred round the individual box argon recirculator described by R. Pascard and R. Fabre (France) (Fig. 2). In this a reduction furnace using Ti/Zr alloy turnings at 800°C is coupled with an argon reservoir and pumping system which circulates the argon and maintains the box at a constant negative pressure. The Ti/Zr turnings can be used completely as the oxide formed is non-adherent.

Need for prefabricated boxes

On general design and commissioning of boxes the need for close cooperation between engineering and scientific staff was clear. The installation of any large scale equipment inside a box calls for a full scale design project, even where the apparatus is standard laboratory equipment. Such projects take time to complete and there is apparent a genuine need for a simple prefabricated unit to be used in conjunction with equipment specially developed in the laboratory and simplified to demand the minimum use of engineering design and construction services.

Summarizing briefly, in addition to the exchange of information on general techniques several important points have been clarified. Of these the most important were the definition of levels at which containment becomes

necessary ; the flexibility of the free-standing glove box used in conjunction with appropriate frogman facilities ; the need for dry inert atmospheres for plutonium handling, and the need for readily available prefabricated glove boxes in addition to fully engineered installations which require the fullest cooperation between engineering and scientific staff in design and take time to install.

In introducing the second part of the conference, that covering shielded installations, J. R. Harrison (Harwell) gave an admirable summary of the theoretical methods and data available for determining shielding requirements, with a view to obtaining the most economic wall thicknesses necessary. The calculations covered wall build-up factors and the frequently neglected problem of air scatter from unroofed boxes.

A nomogram for rapid estimation of the shielding required for a mixed fission product source was also described by a Harwell delegate. From this the shielding appropriate to any isotope can be deduced provided the attenuation of its gamma rays in the shielding is known. This will be available commercially. No direct comparison between theoretical and practical data is available, but theoretical calculations based on a point source in the worst position should, according to Harrison, overestimate the shielding.

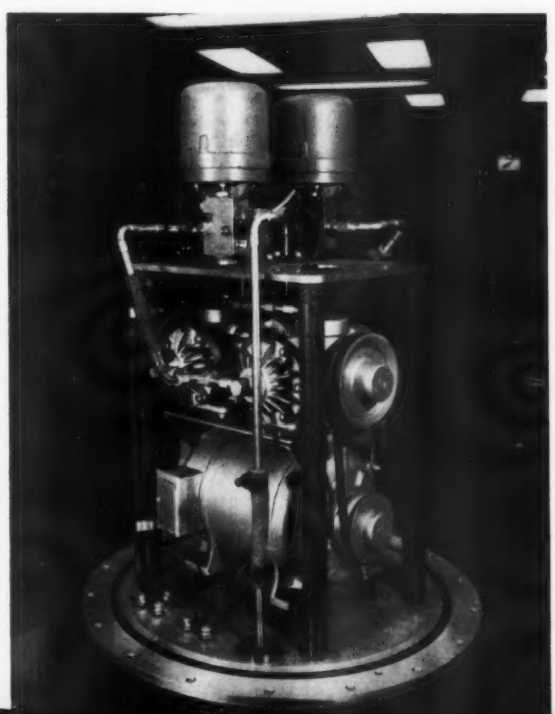
Advantages of lead shielding

Two types of facility are available for beta, gamma work ; the lead-shielded cell, usually used in conjunction with the alpha-box, and the concrete cell. Papers by UKAEA delegates described the use of the former for the development of high temperature reactor fuel processing and for metallographic examination of irradiated fissionable materials, and the latter for handling 1000 MeV curie caesium 137 sources.

Discussion on the relative merits of the two types of facility was largely precluded by clearly presented paper by O. S. Plail (Harwell).

The advantage of lead shielding lies in the relatively low wall thickness necessary. Up to 10 in. wall thickness, i.e. up to activity levels of $\sim 10^3$ MeV curies, handling can be performed by through-the-wall tongs pivoted in a lead ball and socket joint. This system can be adapted by a relatively simple p.v.c. gaitering system to operate

Fig 2 An individual glove box recirculator (France)



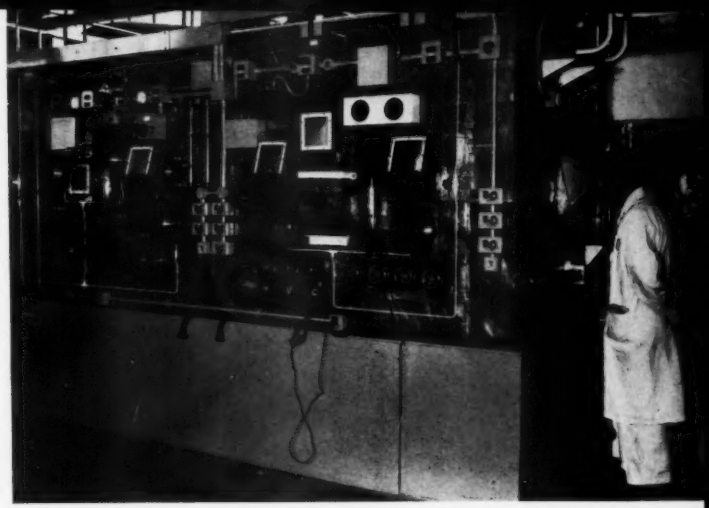


Fig 3 A lead shielded beta-gamma cell for high temperature reactor fuel processing

through the face of an inner alpha box. The restricted coverage of the tongs however means that the cell must usually be built round fixed facilities with drives and controls grouped for operator convenience (Fig 3). Installation of new equipment is virtually impossible without dismantling the box and regrouping the handling facilities. Similarly for maintenance decontamination must be carried out to a level where one wall of the cell can be removed and the inner box withdrawn to a frogman facility.

With 10 in. of lead a window thickness of 16 in. lead glass is required for equivalent shielding. This size of window limits the field of view and protrudes into the operator's area. The disadvantages of radiation darkening, experienced formerly, have however been overcome by the use of CeO_2-stabilized glass, or by annealing out the damage either by thermal cycling or ultra violet radiation.

Remote handling manipulators

With concrete cells, handling is done either by through-the-wall manipulators of the Argonne 8 type*, or where loads greater than about 10 pounds have to be handled, by heavy duty gantry manipulators of the General Mills type. With either of these and operating from one face only reasonable cell coverage is possible. Zinc bromide windows, stabilized to radiation by the addition of either hydrozine hydrobromide or hydroxylamine hydrochloride, or composite lead glass/zinc bromide windows can be matched to the wall thickness. Large apertures are possible. Because of the flexibility of the handling equipment, apparatus may readily be installed or modified. Little restriction is placed on wall thickness and higher external radiation levels may be handled though the difficulty of achieving a seal in the transmission of either the Argonne 8 or General Mills manipulator means that where a toxic hazard is involved the cell must rely on a through draught for containment. In this respect it must be remembered that Dunster recommends complete containment for 0·1–1 curie ' middle aged ' fission products, or 10–100 microcuries ' old ' fission products in the solid form.

Summarizing briefly, where a toxic hazard is involved there is a strong case for lead shielded hermetically-sealed boxes, provided the external radiation level is low enough, i.e. less than 10^3 MeV curies. This covers most experimental irradiations. Where large components and a high external radiation level is expected concrete cells are necessary and a through draught relied on for toxic hazard control.

* A British version is described on p 144

Photos: UKAEA copyright

Almost complete on February 27, the excavation for No 1 reactor

BERKELEY a progress report

RAPID PROGRESS is reported from the Berkeley site in Gloucestershire where one of the Central Electricity Authority's first nuclear power stations is under construction by the AEI-John Thompson Nuclear Energy Co Ltd. Site work is under the control of the Resident Engineer Mr D. Lumbard, and his staff ensure that all work conforms to the requirements of the head office at Radbrooke Hall, Knutsford, Cheshire.

The civil consulting engineers are W. S. Atkins and Partners, London, and the civil engineering contractors are Balfour, Beatty and Co Ltd and John Laing and Son Ltd. Construction of the turbine hall, temporary housing, off-shore works and associated civil work is being done by Balfour Beatty, while John Laing are responsible for the civil engineering constructional work of the reactors and heat exchangers.

The station will comprise two natural-uranium, graphite-moderated, gas-cooled reactors supplying four 85MW turbines. The total sent-out capacity will be not less than 275MW and will probably approach 300MW. A full description of the project appeared in NUCLEAR POWER, February, 1957.

The site generally is to be raised 10 ft, to bring it above the level of the highest tide in the Severn estuary. This is being done by utilizing the spoil from the excavations and by importing quarry wastes. By the middle of March, some 129,000 tons of quarry fill had been brought in at a rate of over 4,000 tons a day.

Excavations for No 1 reactor—the one nearest the shore—have been completed and involved the mucking out of some 72,000 cubic yards of clay and marl. Concrete blinding was then carried out over the whole excavation and the next stage was the erection of two Monotower cranes on prepared foundations. The towers will be 120ft high and the jibs will extend to 240ft above ground level. Meanwhile, excavation of no 2 reactor site is well under way and will be finished shortly.

The turbine hall site is the scene of the biggest excavation at Berkeley. The pit will be 650ft long and 66ft wide and extend down to 40ft below flood water level. The total excavation will amount to about 107,500 cubic yards of which about 12,500 cu yd. had been removed by mid-March. The pit is being kept dewatered by means of 10 well points extending down to 150ft, placed round the area.

Six hundred feet out in the estuary there will be a

Limited supplies of this 36in. by 24in. full colour cutaway drawing of Berkeley No 1 reactor are available unfolded from: Nuclear Power, 3 Percy St, London W1 Price 2s. each, post free

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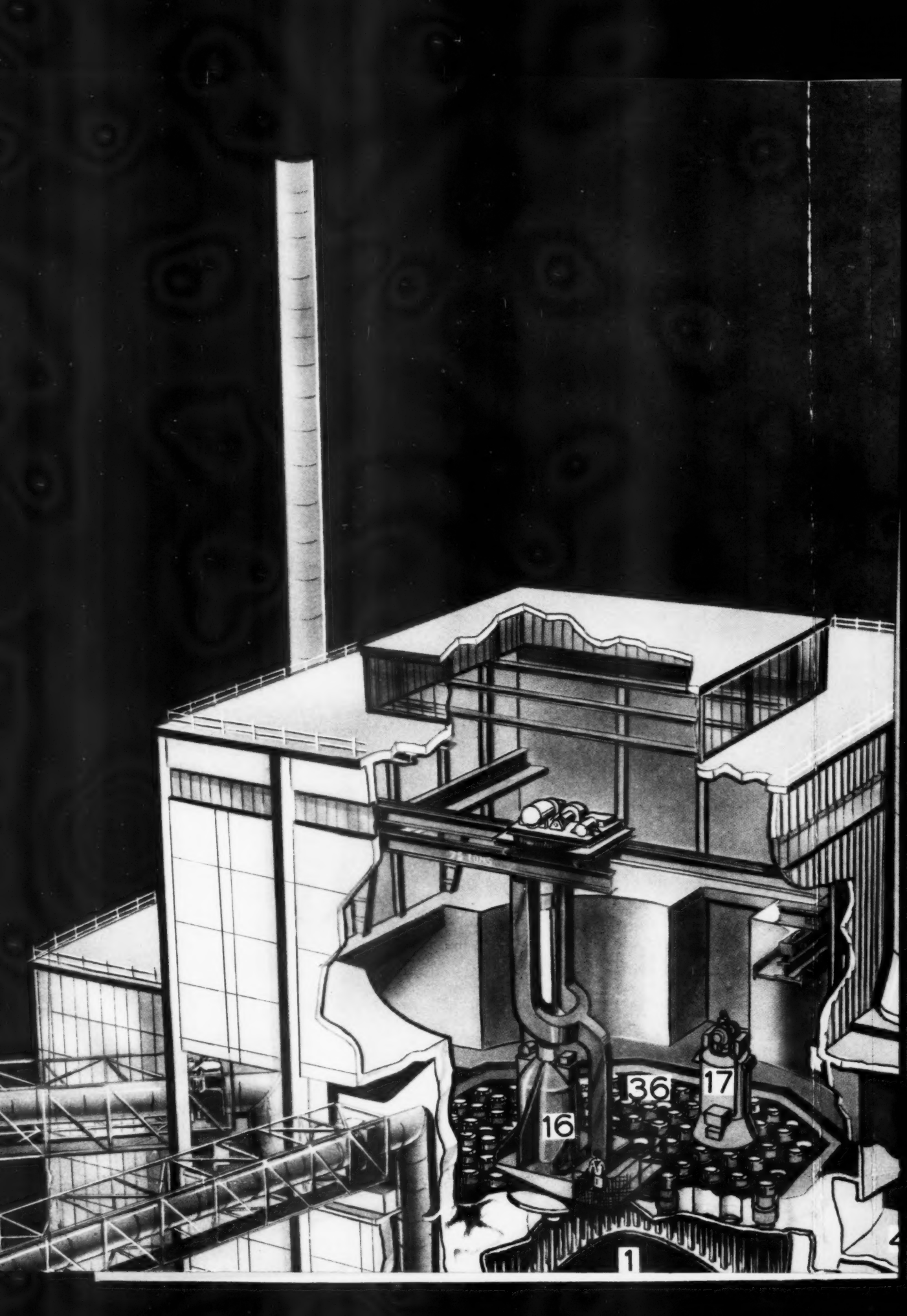
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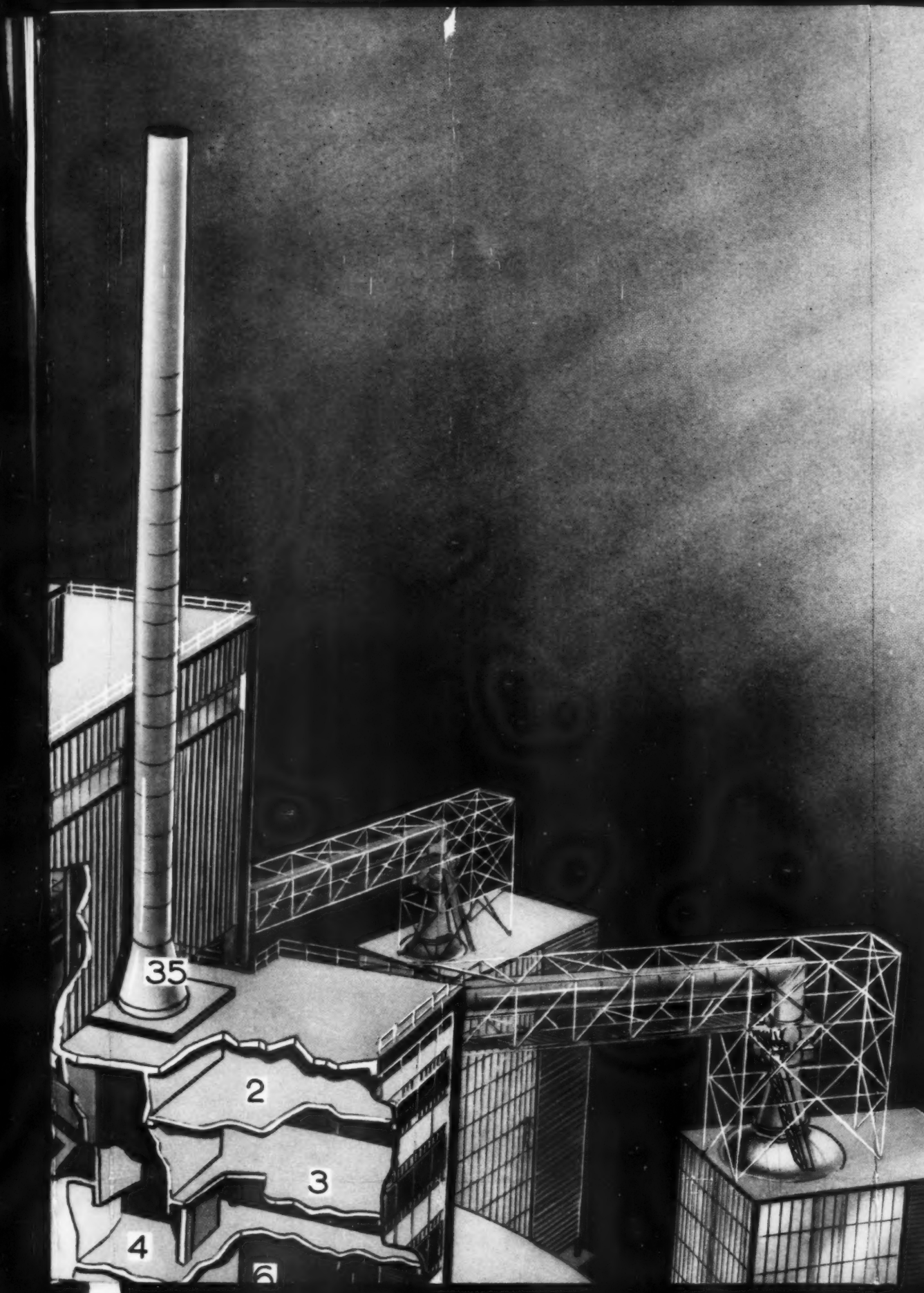
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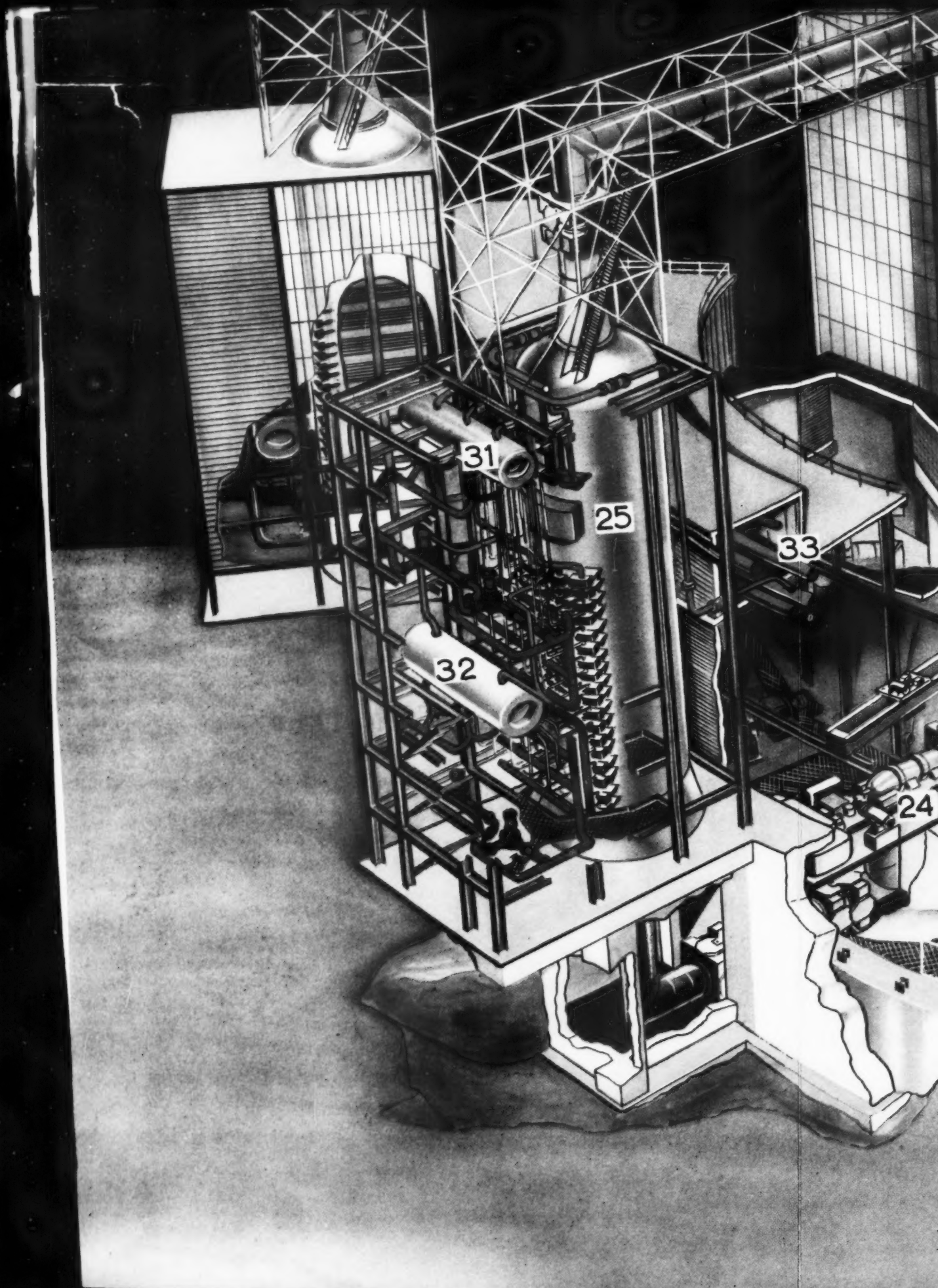
KEY

1. Pressure vessel
2. Storage
3. Fuel element preparation and inspection
4. Exhauster fan room
5. Suction chamber
6. Instrument air compressors and receivers
7. Burst slug detection centre
8. Air lock
9. Wigner control centre
10. Ion chamber room
11. Showers
12. Change rooms
13. Main entrance hall
14. Switchgear
15. Main gas valve operating room
16. Fuel chute machine
17. Charge/discharge machine
18. Charge chute
19. Fuel elements

20. Thermal cooling duct
21. Diesel generator
22. CO_2 filter
23. CO_2 dryer
24. Axial flow gas blower
25. Heat exchanger (one of eight)
26. Cable trench
27. CO_2 gas valve
28. CO_2 inlet duct
29. CO_2 outlet duct
30. Expansion joint
31. High-pressure steam drum
32. Low-pressure steam drum
33. Steam mains to turbine hall
34. Steam main duct
35. Thermal shield cooling stack
36. Control rod drives
37. Core support grid
38. Biological shield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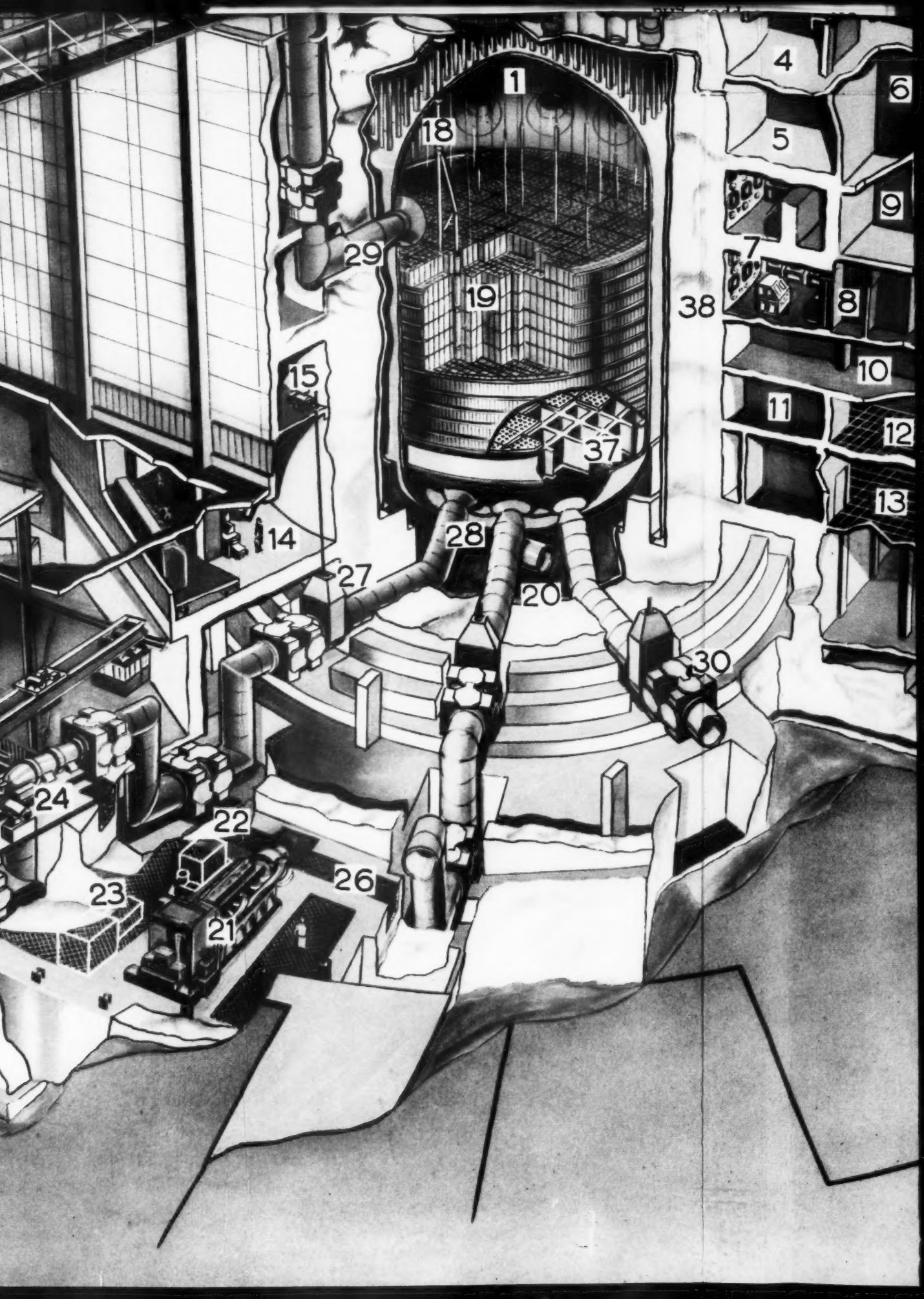
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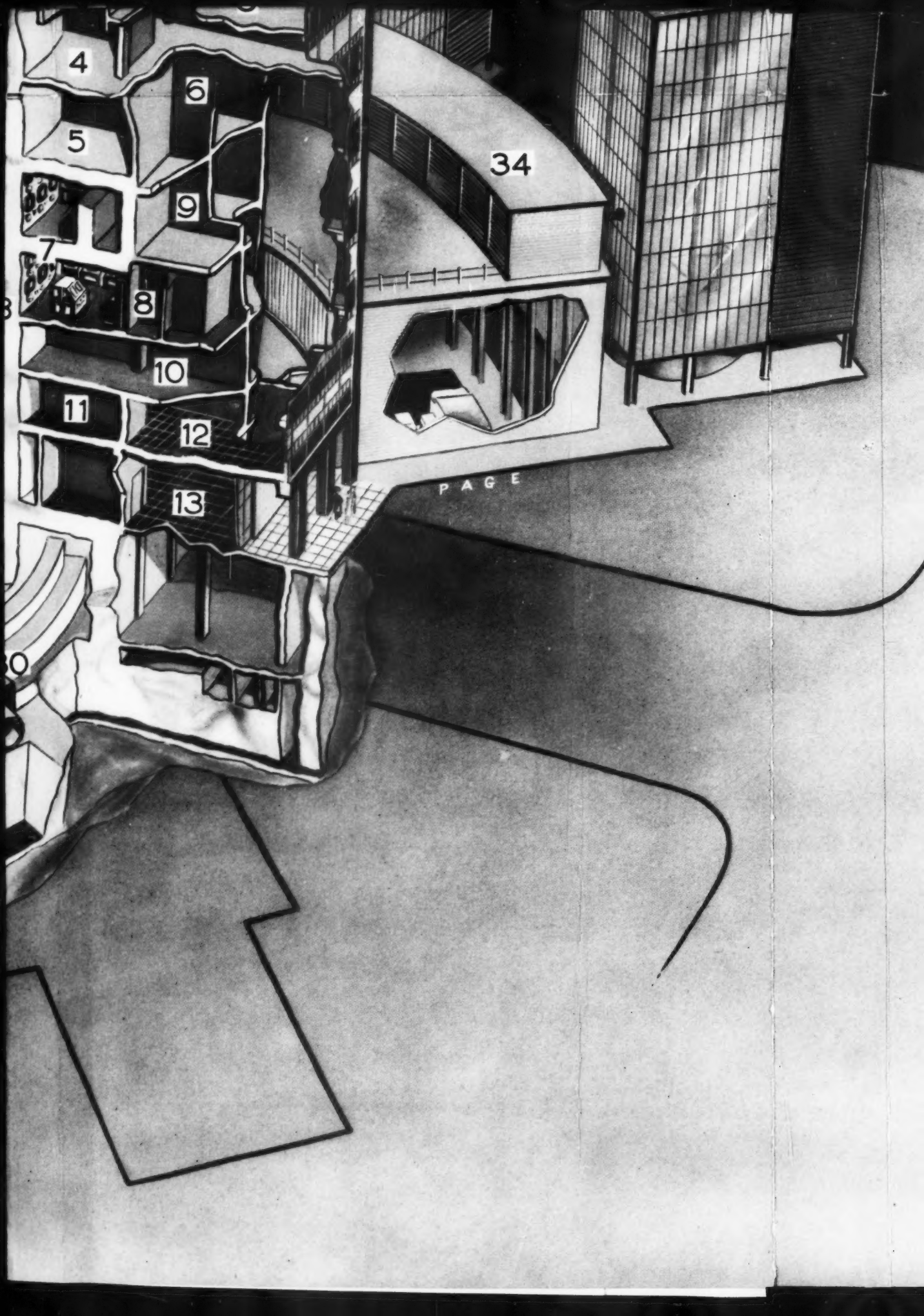
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DESIGNERS & MAIN CONTRACTORS

AEI-John Thompson Nuclear Energy Com

Constituent members of the Company and their part in the Berkeley proj

THE BRITISH THOMSON-HOUSTON CO LTD:	gas blowers, motors, and station transform tors; station control e
METROPOLITAN-VICKERS ELECTRICAL CO LTD:	turboalternators, spe
JOHN THOMPSON LTD:	reactor pressure ves heat exchangers

associated with the Company in this project are:

BALFOUR, BEATTY AND CO LTD:	civil engineering
JOHN LAING AND SON LTD:	civil engineering

Civil Consultants to the Company: W. S. Atkins and Partners. Quantity Su & Theobald

The Central Electricity

BERKEL

Nuclear Power Station, nc

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38. Biological shield

CONTRACTORS

uclear Energy Company Limited

d their part in the Berkeley project are:

:	gas blowers, motors, and control gear; grid and station transformers; control rod actuators; station control equipment
LTD:	turboalternators, special instrumentation
	reactor pressure vessels, thermal shielding, heat exchangers

t are:

	civil engineering
	civil engineering

Atkins and Partners. Quantity Surveyors: Messrs Gardner

lectricity Authority

KELEY

Station, no. 1 Reactor

Power nuclear engineering 3 Percy Street, London, W.1

Early in March, the turbine hall pit. It will eventually be 650ft long

brisk tempo at CEA power station site

quarter-mile-long sheet steel piled baffle wall parallel to the shore, separating the intake works for the circulating water from the outflow. The tidal range is 37ft and, to ensure water at all stages of the tide, a wide channel will be dredged to about ¼ mile from the intake. The pump house will be located immediately behind the sea wall and will be excavated down to 60ft. From here 9ft. dia. tunnels will be driven out to the intake shaft. Owing to the poor bedrock, these tunnels will be driven in compressed air. The outfall culvert from the condensers will run out to a point on the shore side of the intake wall.

A central concrete weighbatching plant has been set up to supply the whole site. This comprises two 2 cu. yd mixers and will supply 80 cu. yd an hour.

The construction camp covers 9½ acres and is planned to accommodate 650 men in double cubicles in centrally-heated huts. There will also be accommodation with single rooms and 44 bungalows for married staff. There will be full canteen and recreational facilities including games rooms and a concert hall. The camp in fact is to be a small town complete with shop, laundry, Post Office and hospital.

At the middle of March the labour force was over 700, of whom 490 men have been recruited from the Gloucester, Bristol and Berkeley areas.

Meanwhile at the John Thompson Ltd works at Wolverhampton, 3in. thick steel plate sections for the 50ft dia, 80ft high pressure vessels are already waiting. Thompsons will be starting site erection of these in a few weeks time.

Leading data of the Berkeley power station

CORES
Two. Pure graphite, 22-sided prism, 48ft dia. 30ft high. 3,000 fuel channels

FUEL
Natural uranium bars, canned in Magnox alloy. Elements individually supported. Charged and discharged on load

PRESSURE VESSELS
Cylindrical with ellipsoidal ends. 50ft dia, 80ft high, designed for 125 lb/in² static CO_2 pressure, 3in. thick steel

HEAT EXCHANGERS
Eight per reactor. Vertical cylindrical, 17½ft dia, 70 ft high. Each contains economizer, evaporator and superheater sections of extended surface tubing

GAS BLOWERS
One per boiler. Axial-flow, driven by 3,000 h.p. a.c., squirrel-cage induction motors through variable-speed hydraulic couplings

GAS CONDITIONS
Mass flow per reactor, $22{\cdot}3 \times 10^6$ lb/h. Inlet temp to reactor, 320°F: outlet, 662°F.

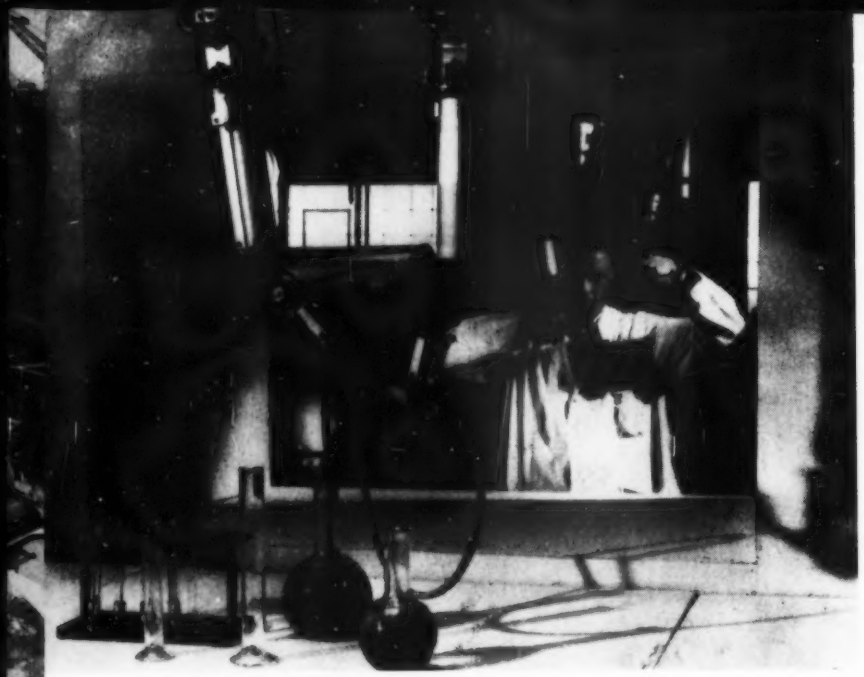
STEAM CONDITIONS
high pressure: 320 lb/in² abs, 612°F
low pressure: 77 lb/in² abs, 612°F.
mass flow (per reactor to two turbines) h.p. 1,120,000 lb/h
l.p. 520,000 lb/h

TURBINES
Four 85MW Metrovick 2 cylinder impulse machines

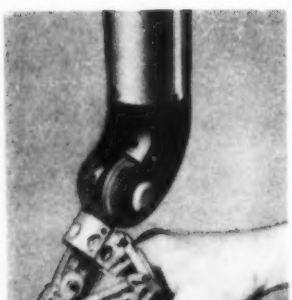
OUTPUT
Minimum guranteed, 275MW (sent out)

THE CONSTITUENT COMPANIES OF THE AEI-JOHN THOMPSON NUCLEAR ENERGY CO LTD ARE:
The British Thomson-Houston Co Ltd, Metropolitan-Vickers Electrical Co Ltd and John Thompson Ltd.
The firms of Balfour Beatty and Co Ltd and John Laing and Son Ltd are associated with the Company for civil engineering work on power stations.

Full remote control of hot cells planned



An operator shows how a suction pipette may be handled inside a hot cell with the slave manipulator

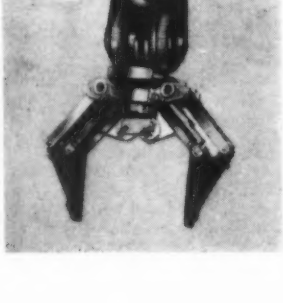


The operator's thumb fits into a cylindrical tube and another pair of tubes are provided for the first two fingers

A MASTER SLAVE MANIPULATOR, developed by Savage and Parsons Ltd, in conjunction with AERE, Harwell, is now available to commercial users. Last month, NUCLEAR POWER was invited to the firm's works at Watford to see a demonstration of the equipment, shown in combination with a closed circuit stereoscopic television unit, developed for this purpose by Marconi's Wireless Telegraph Co Ltd. Known as the SP Model 8, the manipulator is designed to perform delicate handling operations with highly active materials in hot cells or dry boxes, and is claimed to be capable of performing all the operations normally requiring human hands. The demonstration showed it transferring the contents of a flask into a test tube, operating a suction pipette and unscrewing the lid of a small bottle.

Made of light alloy and stainless steel, the manipulator is said to have 500 moving parts, including 200ft of stainless steel tape. Friction losses are reduced to a minimum by the use throughout of miniature ball bearings and control loads are minimized by counterbalancing. The boom, or vertical arm, is extendable 3ft and when half extended the force required to initiate movement in a lateral direction is about 1oz. With the jaws in the horizontal position, the torque required to rotate the hand-piece and the jaws is about 8in. oz.

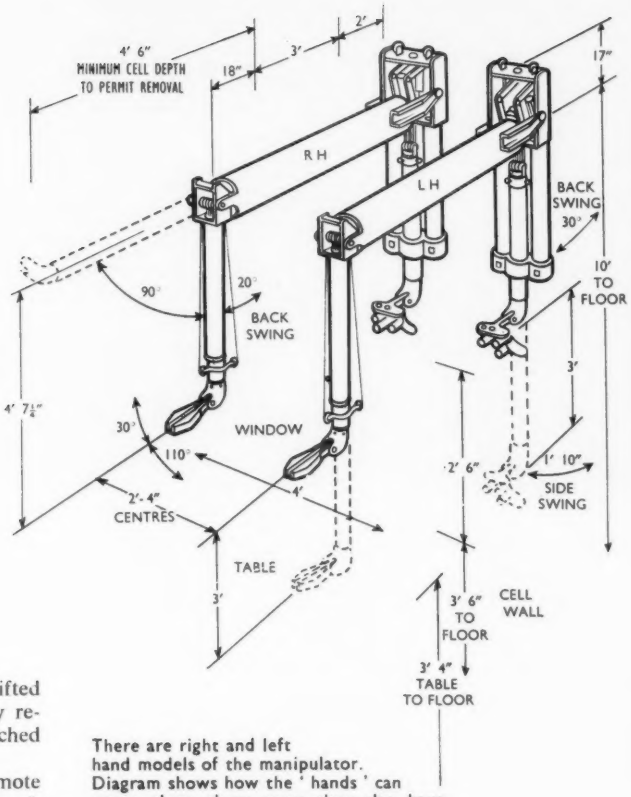
The slave ' hand ' consists of tongs, the jaws of which move together on parallel-motion linkages when the finger pieces at the operator's end are squeezed



The hand-piece at the operator's end consists of a rubber-covered pistol-type grip which fits into the palm of the hand, with a cylindrical tube fixture for the thumb and a pair of similar tubes for the first two fingers. There are, of course, right- and left-hand models. Extension of the boom and rotation in two planes and swing, twist and tilt of the tongs unit are achieved by appropriate movement of the whole hand piece. The slave ' hand ' consists of a pair of steel ' fingers ' mounted on parallel linkages. The action of these jaws is controlled by the operator by a squeezing action between the thumb and first two fingers.

As an example of the manipulator's performance, it is said that a weight of 5lb can be gripped between the jaws and manœuvred fairly easily for short periods. A

Combination of mechanical handling and 3-D television demonstrated. Next step will be abolition of all mechanical links



There are right and left hand models of the manipulator. Diagram shows how the ' hands ' can move along three axes: they also have three degrees of freedom for rotations

7lb weight would be the maximum that could be lifted between the jaws. Greater weights can be carried by removing the jaws and suspending them on wires attached nearer the pivot point.

The manipulator demonstrated at Watford gave remote control at a distance of 5ft 6in. and was viewed through a glass screen. As research advances, the size of hot cells is likely to increase and it may not be possible for the operator to see into every corner of the cell. For such situations and to give a detailed close-up view of the experiment, Marconi's have developed, at the request of the AERE, a stereoscopic television unit for experimental purposes. A further development in prospect is the actuation of the slave manipulator by servomechanisms, and by this means remote handling at distances of half a mile or more will be possible. In such an installation, the perspective given by the stereoscopic television should make manipulation as easy and as accurate as with direct vision.

The stereoscopic camera channel consists of two industrial television cameras, two control units and two standard, medium-grade studio display monitors with 14in. screens. The cameras are mounted side by side with inclined lines of sight intersecting at an adjustable point of interest, giving binocular vision on the two monitors. These are mounted at right angles in the cabinet, and each screen is covered with a polarized filter, one polarized in the horizontal plane and the other in the vertical. The two pictures are superimposed on a semi-silvered mirror mounted at 45° to each monitor. When viewed through polarized spectacles, the stereoscopic effect is obtained. There is considerable light loss in the polaroid and the half-silvered mirror, and the final intensity is only about 10% of that of the source. This is compensated by using a high intensity light source resulting in a screen brightness of 5 to 10 ft lamberts. The depth of focus obtainable depends on the intensity of the light source.

Our reporter used the manipulator to perform the simple operation of transferring the contents of a test tube to a flask and got the impression that it would not take long to learn to use it with dexterity.

With his back to the hot cell, the operator watches the actions of the slave hand in the stereoscopic television monitor

The computer designed and built by Elliott Bros (London) Ltd for the GEC Simon-Carves Atomic Energy Group. Here is a full description of the machine

An electronic

AN ANALOGUE COMPUTER enables a physical system to be simulated in the laboratory in such a way that its dynamic performance can be investigated. It allows the examination of all the variables of interest, and design parameters can be changed at the turn of a knob and the effect of their variation observed. It is easy to see that where reactor safety is concerned, for example, this is a very powerful method for ensuring that the results of failure are known before construction is started. One of the many problems which fall into this category is that of reactor emergency shut-down. Due to the inertia of the shut-off rods a finite time must elapse before they take full effect and the reactor becomes sub-critical. It is essential that this time interval is not so long that the temperature reached in the fuel elements results in weakening, melting or even igniting the canning material. On the other hand, by ensuring that the rods are inserted as fast as possible, an unnecessarily complicated mechanical design may be required. It is possible with an analogue computer to study problems such as these, displaying the results in graphical form.

There are two main approaches to the study of such problems. One is to set-up the differential equations in a suitable form for solution by analytical methods. But for any complex problem these methods are usually difficult, and sometimes impossible, even although numerous simplifying assumptions are made. By using an electrical analogue of the system, its behaviour can be examined under various conditions and quite complex problems can be investigated, often with less simplifying assumptions than would otherwise be necessary.

A note on analogue computing (refs. 1 & 2)

In setting out to solve a problem the first thing to be done is to draw a block schematic diagram of the physical system to be studied. It may be necessary to break down the system into many different 'blocks' in order that the next step may be taken—the formation of dynamic performance equations for each part. Having done this, an electric circuit is designed for each block, such that the circuit has the same performance equations as those of the system it represents. These individual circuits are then connected according to the original block schematic.

These can then be set up on the computer and are connected so that when appropriately energized they will simulate the dynamic behaviour of the real system. Measurements can then be made and curves plotted either manually or automatically. When the measured electrical quantities have been multiplied by the appropriate scale factors they represent the results of the real problem under consideration. The computer may operate in real time, in which case actual system components can be incorporated as desired, or its operation may be speeded-up when studies involving long term changes are undertaken. This latter facility is used for instance when simulating a start-up procedure with the reactor power output rising from perhaps a few watts to several hundred megawatts; in practice this may take several hours but the computer can be set to operate so that one second computing time is equivalent to one minute real time.

Computing units and circuits

The most important unit in the machine is the high-gain direct-coupled amplifier (Fig 1) which may be used for adding, integrating, or for other operations by suitable connexion with resistors and capacitors. Typical basic circuits are shown in Fig 2. The differentiator is shown for completeness although in practice it is seldom used since it amplifies any spurious electrical noise voltage, which is undesirable. The equations are, therefore, usually arranged so that integrators may be used in preference to differentiators.

Whenever multiplication of two or more variables is required, a multiplying device other than a d.c. amplifier (which can only multiply by a constant) is required. These may be electronic devices which have a high frequency response, or electro-mechanical. In this computer the latter type is used and consists of a servo-driven potentiometer with a number of gangs (Fig 3).

Special problems

Certain characteristics of nuclear engineering problems have to be considered in the design of a computer. Some of these are mentioned below.

1. For reactor start-up, a large range of output powers must be covered (often as many as 8-10 decades). This means that the computing d.c. amplifiers have to be designed for a low drift rate ('drift' is a random variation with time of the amplifier output. It has several causes, including changes in the valves and

In the design stages of a reactor, the analogue computer provides a rapid and economical method of solving complex performance calculations.

reactor simulator

ROSS CAMERON, BSc(Eng), AMIEE
Nuclear Division, Elliott Bros (London) Ltd

D. A. AUSTIN
GEC Simon-Carves Atomic Energy Group

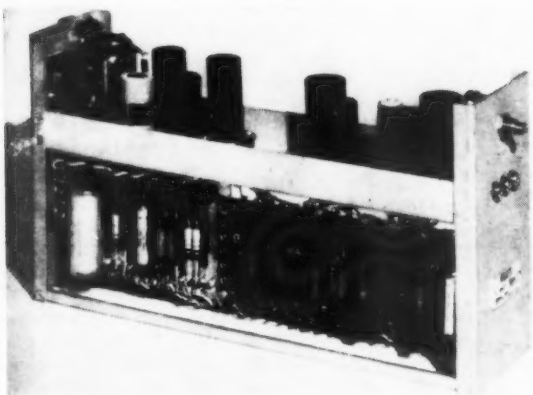


Fig 1 Basic unit is the high-gain direct-coupled amplifier

components during their life and changes in supply voltages). In general, it is not possible to make amplifiers completely free from drift and in this case a chopper corrected system is used and there is a drift of less than ± 100 μV over a day. The standard amplifier has an output range of ± 100V and its useful range is therefore from ± 10 mV to ± 100 V for an error of ± 1 per cent (Fig 1). In order that there is no chance of computation proceeding after any amplifier has reached saturation, so introducing errors, it is arranged that as soon as any amplifier reaches ± 100 V, all amplifiers acting as integrators have their inputs disconnected and the integrating capacitors are isolated so that their charge is maintained. In a computation covering many decades, these voltages are then measured, reduced by a known proportion and the computation restarted. As well as stopping automatically at the limits of the amplifiers, the computation may be stopped by a press-button or by a stop clock.

2. The problems may last a considerable time, say as long as a few hours for start-up and several days for

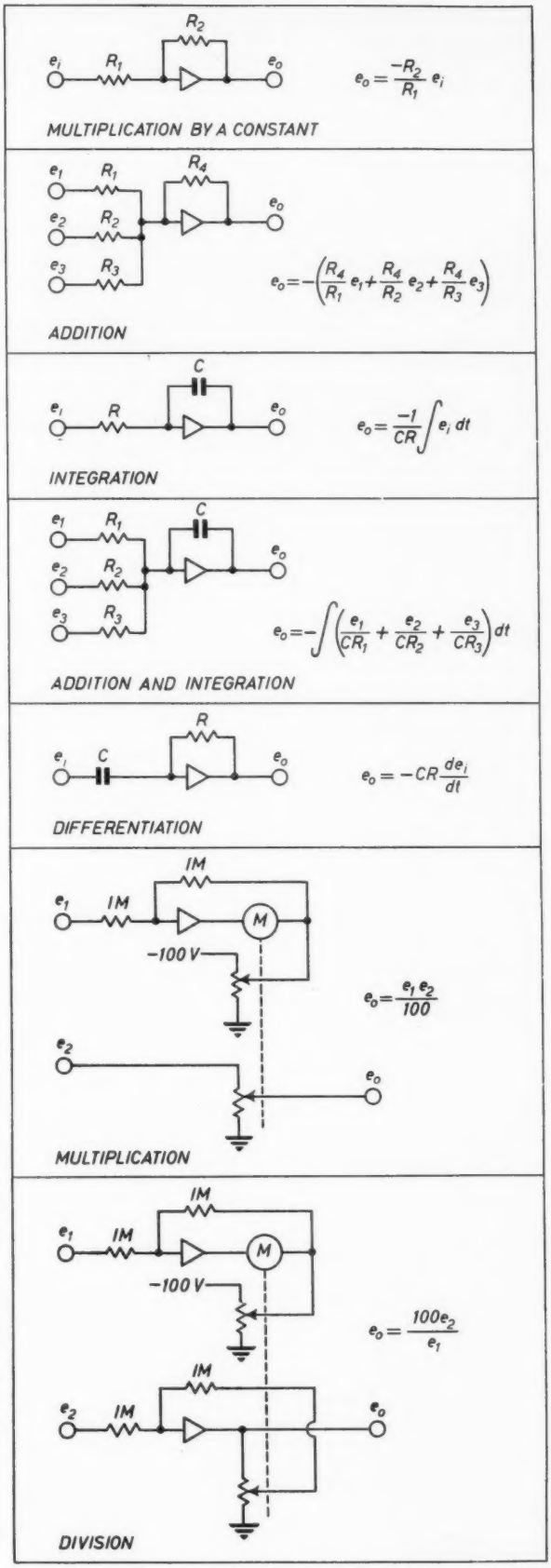


Fig 2 Circuits for basic mathematical operations

LORSQU'ON PRÉPARE le projet d'une station électrique nucléaire, il est important qu'on en examine la marche pour de différentes conditions de travail. Les méthodes de la mise en marche et de la fermeture, manuelles ou automatiques, doivent être comparées du point de vue de sécurité et commodité. Il est indispensable d'examiner les effets des pannes partielles ou totales de diverses parties de la station afin de pouvoir établir si l'on a satisfait à toutes les exigences de sécurité. On doit étudier la variation des paramètres de construction afin d'établir les valeurs optimum et les variations permissibles; de même on doit établir si l'incorporation des systèmes de contrôle automatiques est désirable pour certains buts. La machine à analogie fournit une méthode rapide et très commode pour résoudre la plupart des problèmes fort complexes rencontrés dans une investigation de cette sorte. Cette machine est aussi économique au point de vue du temps, frais et efforts; elle permet de corriger toutes les importantes erreurs de l'avant-projet avant que la construction ne commence.

WENN MAN den Entwurf eines Atomkraftwerkes vorbereitet, ist es wesentlich, die Gesamtleistung für die mannigfaltigsten Arbeitsbedingungen zu untersuchen. Sowohl die mit der Hand verrichteten als auch die automatischen Ingangsetzungs- und Eistellungs-Verfahren müssen vom Gesichtspunkt der Sicherheit und Zweckdienlichkeit verglichen werden. Die Resultate des teilweisen oder totalen Versagens verschiedener Teile der Anlage müssen untersucht werden, damit man feststellen kann, ob allen unentbehrluchen Sicherheitsbedingungen gerecht geworden ist. Man muss die Veränderungen der Konstruktionsparameter untersuchen, um die optimalen Werte und zulässige Veränderungen festzustellen; man muss ebenfalls feststellen, ob Einverleibung selbsttätiger Steuerungssysteme für gewisse Zwecke erwünscht ist. Ein Analogie-Gerät beschafft eine rasche und sehr bequeme Lösungsmethode für die Mehrheit der ziemlich komplizierten Probleme, den man in einer derartigen Untersuchung begegnet. Das Gerät erspart gleichfalls Zeit, Geld und Mühe, und ermöglichtes, beliebige bedeutende Konstruktionsfehler zu beseitigen, bevor der eigentliche Bau beginnt.

AL DISEÑAR una central electroatómica es necesario examinar la eficiencia total para varias condiciones de funcionamiento. Los sistemas de puesta en marcha y de parada, bien sean manuales o automáticos, deben compararse bajo los puntos de vista de seguridad y conveniencia. Hay que examinar los efectos de una falla parcial o completa de los diversos elementos de la central, con objeto de comprobar si se satisfacen todas las condiciones de seguridad requeridas. Se necesita investigar la variación de los paraámetros del diseño para establecer los valores óptimos y las variaciones permisibles; y tiene que comprobarse la conveniencia de incorporar sistemas automáticos de control para ciertos propósitos. Un computador de analogía provee un método rápido y muy útil para la solución de la mayoría de los problemas bastante complejos que presenta una investigación de esta clase. Asimismo, ahorra tiempo, gastos y esfuerzo, y permite la corrección de cualquier error importante en el diseño, antes de principiar la construcción.

ПРИ КОНСТРУИРОВАНИИ ядерной силовой станции необходимо исследовать ее действие при разных рабочих состояниях. Операции запуска и выключения, ручные или автоматические, нужно сравнивать с точки зрения безопасности и удобства. Следствия частичной или полной неисправности разных частей установки нужно исследовать для того, чтобы можно было найти, удовлетворены ли все требования безопасности. Необходимо изучать изменение конструктивных переменных, чтобы установить оптимальные значения и допустимые изменения; кроме того надо установить, желательно ли в некоторых случаях включить автоматические системы управления. Моделирующее устройство обеспечивает быстрый и весьма удобный метод решения большинства довольно сложных проблем, встречаемых в исследованиях этого рода. Это устройство сберегает также время, деньги и труд, и позволяет исправлять важные конструктивные ошибки еще до начала стройки.

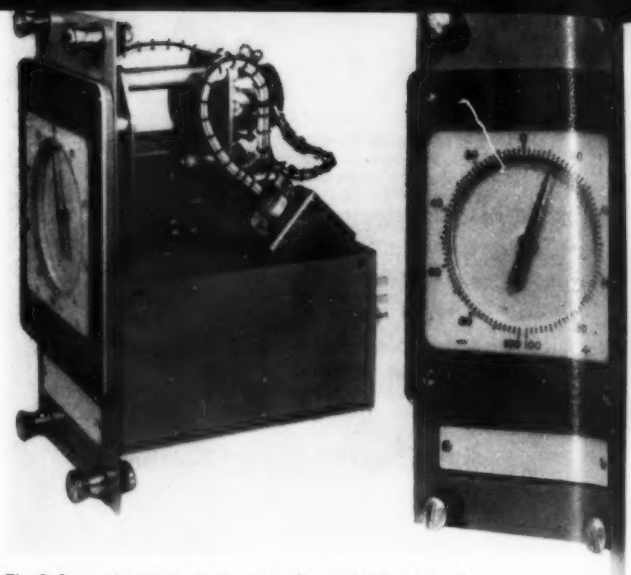


Fig 3 Servo-driven potentiometer for multiplication of two or more variables

fission-product poisoning. In the latter case it is impracticable to compute in real time and the computation is speeded up, sometimes by as much as a factor of 3600; i.e. a second for every hour.

3. It is often necessary to multiply a quantity by several others. For the type of problem under consideration, the frequency response of the multiplier does not have to be very high and an electro-mechanical multiplier gives an adequate performance. In the one used, a very low friction potentiometer is driven by a low inertia motor and when adjusted for the best step response gives a natural frequency of about 11 c/s. a phase lag of 16° at 2 c/s and a response time, to a step input, of 60 millisec. for 10 per cent overshoot. Curves of the amplitude and phase response are shown in Fig 4. As many as five quantities may be multiplied by one other quantity. An advantage of using a lightly loaded system is that a standard computing amplifier drives the motor direct.

4. In the transfer of coolant between heat exchangers for example, thermal time lags exist which vary with the flow rate and some means of simulation is required. Many methods have been suggested and the most suitable one depends on the time lag required and whether it has to be smoothly varied. In this application, smooth variation over a range of 2-60 seconds was called for and the method chosen uses capacitors as the storage medium. One hundred capacitors are mounted on a disc; each is connected to two magnetically operated contacts, the signals being 'read in' via one and 'read out' via the other. Two small permanent magnets, mounted on arms attached to a servo-driven shaft, are used to operate the contacts. The magnets are so arranged that each 'read out' contact is closed when the shaft has made nearly a complete revolution after the closing of the corresponding 'read in' contact. The time lag may therefore be varied by changing the speed of rotation of the magnets. One of the difficulties encountered in this method is that if the capacitors are not to be too large (the ones used are 22,000 pF) the insulation to earth and between capacitors must be above 10^{12} ohms. For this reason Perspex and PTFE are used as insulating materials and the contact assembly is enclosed in a desiccated box.

5. Since the basic reactor kinetics equations are likely to be used in many applications it appeared that it would simplify matters if the components were permanently connected to solve them. The important variables such as excess reactivity, the decay constant λ_i, and the delayed neutron fractions $\mu_i\beta$ are brought to controls on the front panel. This will be discussed later in greater detail.
6. It was envisaged that something like 80 amplifiers would be required for the largest problems and, in order to make most use of the machine when smaller problems were being solved, it was arranged that two completely independent problems could be solved at the same time using any combination of cabinets.

Construction

The computer consists of two special cabinets, one for control, the other for solving the reactor kinetics equations; and six other cabinets which may be connected by external leads to solve the heat exchange, control rod, poisoning and other equations. Each cabinet contains up to fifteen computing amplifiers and three servo-multipliers. Maximum flexibility is achieved by the amplifiers and component boxes being plug-in units. All the amplifier inputs and outputs are brought to desks which also have lines to other cabinets for interconnexions and monitoring. On the control cabinet are two two-pen recorders and all the operational controls. For fast transients, it is preferable to use a cathode-ray tube display and a time-base is provided with four time scales, 10 secs to 0·01 sec.

Examples of the use of the computer

The use of the computer has been confined to investigations of the overall performance of a complete nuclear power station under various conditions of operation. Fault conditions have been investigated in some detail, and the effect of incorporating automatic control systems for the reactor and its associated coolant gas circulators has been studied.

For these studies various sections of the computer are connected to simulate the performance of separate parts of the station, e.g. the reactor, control rod operation, gas coolant circulation, heat exchange within the reactor, main steam raising units, etc. Each separate circuit is then checked for correct operation by itself before interconnexions are added to allow simulation of the performance of the complete station. Some typical computer circuits are described later.

Two computer results are shown (Fig 5) indicating the variation of reactor power output, fuel and can tempera-

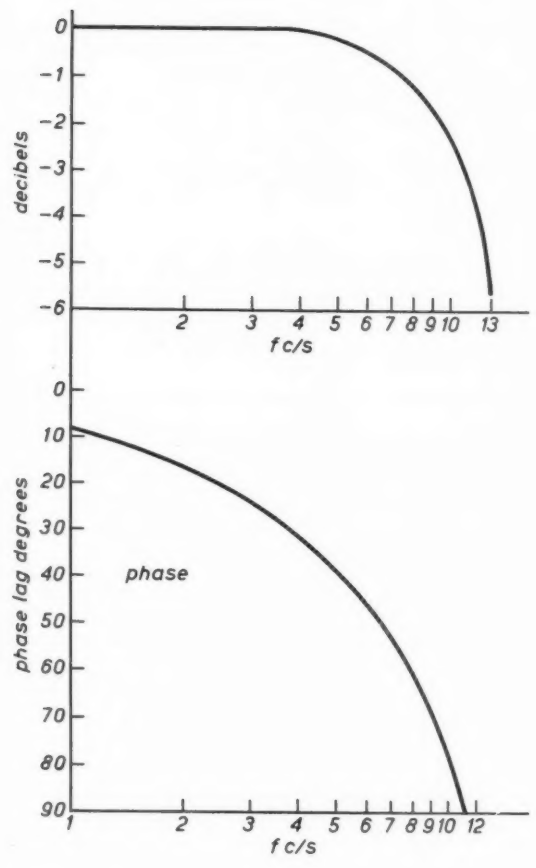


Fig 4 Amplitude and phase response

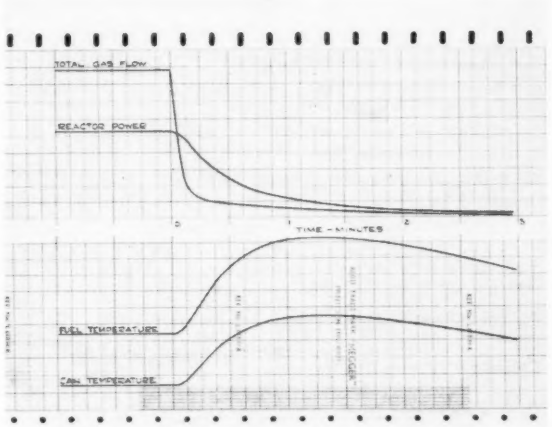


Fig 5 (a) Complete failure of gas circulator

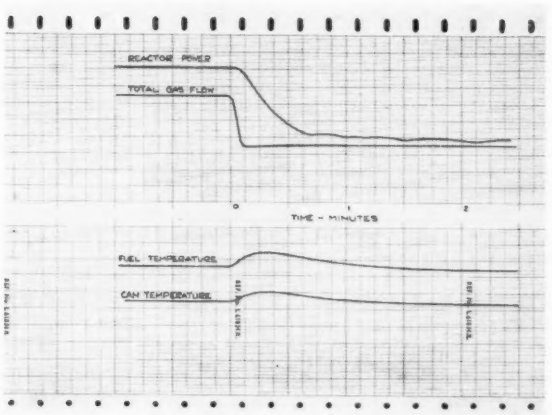


Fig 5 (b) Partial failure of gas circulator

ture for partial and complete failure of power supply to the coolant gas circulator motors.

In each case the failure of all safety devices which would normally operate under these conditions has also been assumed so that the results indicate the worst possible effect of gas circulator failures. No automatic control is incorporated for these cases.

Notes on typical computing circuits

A. Reactor Kinetics

The standard kinetic equations[3] for a point reactor are used. These are:

$$\frac{dP}{dt} = (\Delta k - \beta)\frac{P}{t_0} + \sum_{i=1}^{5} \lambda_i N_i + S \qquad (1)$$

$$\frac{dN_i}{dt} = \mu_i \beta \frac{P}{t_0} - \lambda_i N_i \qquad (2)$$

$$\Delta K = aT_u + bT_m + cN_x + ed_c + fd_f + gd_s + \Delta k_0 \qquad (3)$$

where:

P = nuclear power, or neutron density
Δk = net reactivity
β = fraction of neutrons lost to delayed neutron precursors
λ_i = decay constant of delayed neutron group i
N_i = concentration of delayed neutron group i
$\mu_i\beta$ = proportion of lost neutrons absorbed by group i precursors
t_0 = mean neutron lifetime
T_u = mean uranium temperature
T_m = mean moderator temperature
N_x = xenon concentration
d_c = position of coarse control rods
d_f = position of fine control rods
d_s = position of safety rods
Δk_0 = long term reactivity adjustment
S = source term
$a, b \ldots g$ = coefficients in the reactivity equation

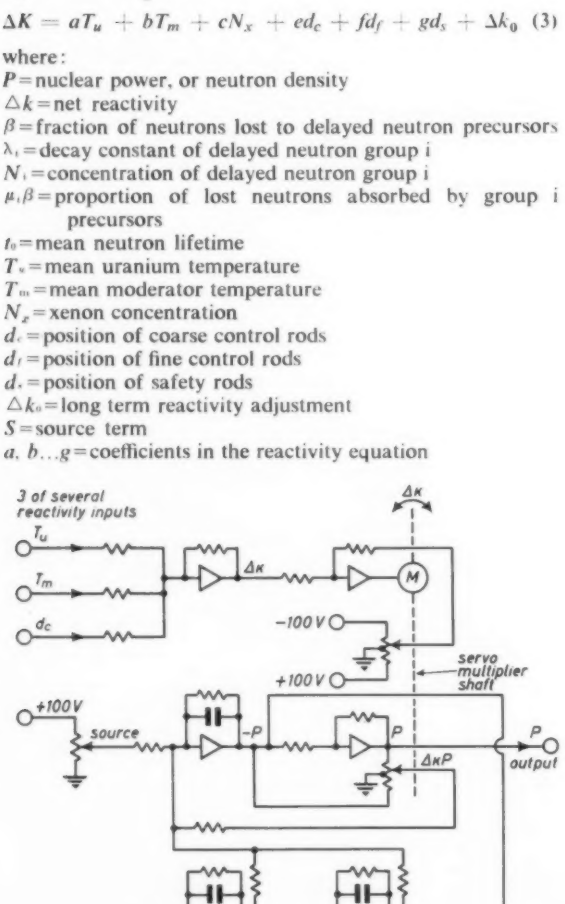


Fig 6 The basic reactor kinetics circuit

The basic reactor kinetics circuit[4] is shown in Fig 6 and a photograph of the desk layout in Fig 7. Some facilities which are included in the final circuit as used in the computer are described below, and the relation between the physical constants and the circuit constants are given in the appendix.

1. A three position switch allows the circuit to be operated in unity time scale, or to be speeded up by a factor of ten or a hundred.
2. Provision is made for switching the maximum range of reactivity to 0.1, 1 or 10 per cent. The lower ranges are required when studies are undertaken involving only small changes of reactivity. The upper range is used when it is necessary to simulate a scram shutdown of the reactor.
3. Potentiometer adjustments are provided so that β, t_0, $\mu_i\beta$ and λ_i can be adjusted.
4. The scale factors of this circuit are so chosen that each of the six initial condition voltages P, N_1 to N_5 are set to exactly the same value for any steady-state conditions. This enables the circuit to be adjusted quickly and accurately to any required steady reactor power output.

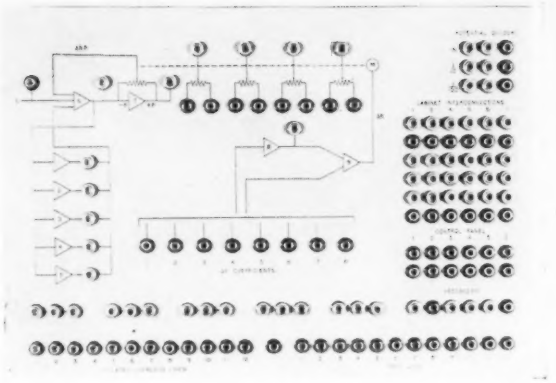


Fig 7 The reactor kinetics desk

B. Coolant gas circulators

A total of eight separate gas circuits are represented by two equations:

$$\frac{dW_x}{dt} = a_x \frac{(H_e)_x}{W_x} - b_x W^2{}_x - c_x(W_x + W_y)^2 \qquad (4)$$

$$\frac{dW_y}{dt} = a_y \frac{(He)_y}{W_y} - b_y W_y{}^2 - c_y(W_x + W_y)^2 \qquad (5)$$

where:

W_x = mass flow in n gas circuits
W_y = mass flow in $(8\text{-}n)$ gas circuits
H_e = electrical power input to driving motors
a, b, c = constants

The constants in each equation are so chosen that each equation represents the dynamic performance of the selected number of gas circuits. This arrangement allows the performance to be evaluated for any partial or complete failure of power supply input to the driving motors, as well as for small variations of power input when automatic control of gas flow is being studied. The circuit is shown in Fig 8.

C. Reactor heat exchange and main steam raising units

No circuits are shown for these, but the computer representation is arranged throughout such that only changes from some arbitrarily chosen temperature are computed. This technique allows the temperature scale factors to be increased and gives improved accuracy.

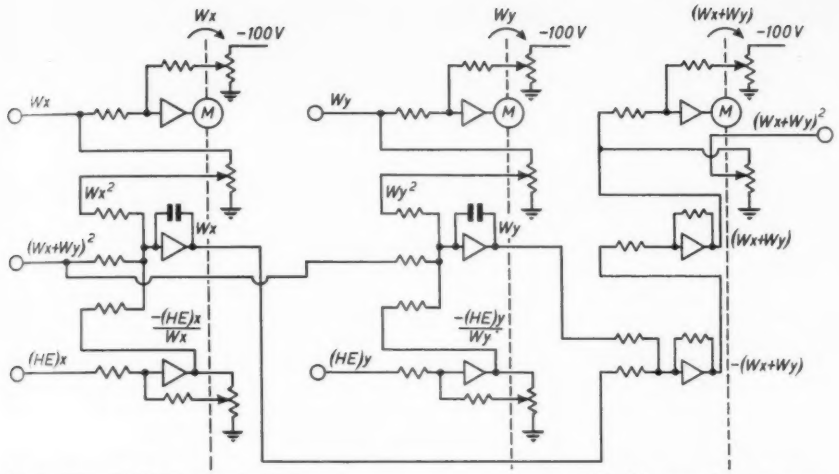


Fig 8 The gas circulator circuit

Accuracy and fault occurrence

Each circuit when checked for computing accuracy against a numerically calculated result has consistently checked to better than ± 1 per cent.

During the first three months of use of the computer the incidence of faults has been quite low. The faults occurring during this period in the computing amplifiers are listed below.

Valves	Resistors	Capacitors	Relays
9	2	2	1

Acknowledgements

The authors wish to express their thanks to their colleagues and to members of the Atomic Energy Research Establishment for their advice during the design stages of the computer. Acknowledgement is also due to the Directors of the GEC Simon-Carves Atomic Energy Group and Elliott Bros (London) Ltd for their permission to publish this article.

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APPENDIX

How the circuit constants are related to the physical constants

$$\frac{dP}{dt} = (\triangle k - \beta)\frac{P}{t_0} + \sum_{i=1}^{5} \lambda_i N_i + S \qquad (1)$$

$$\frac{dNi}{dt} = \mu_i \beta \frac{P}{t_0} - \lambda_i N_i \qquad (2)$$

The above equations are solved using the circuit of Fig 6 which will now be considered in greater detail. The circuit used to solve equation (1) is shown in Fig 9a and the circuit equation is:

$$-\frac{de_0}{dt} = \frac{e_1}{CR_1} + \frac{e_2}{CR_2} + \frac{e_3}{CR_3} + \frac{e_0}{CR_4} \qquad (6)$$

Let $e_0 = -a_p P$ where the scale factors are a_p
$e_1 = a_s P$ at Δkmax. a_p
$e_2 = a_i N_i$ a_i
$e_3 = a_s S$ a_s
} V/unit

Substituting these in equation (6) and dividing by a_p

$$\frac{dP}{dt} = \frac{P}{CR_1} - \frac{P}{CR_4} + \frac{a_i N_i}{a_p CR_2} + \frac{a_s S}{a_p CR_3} \qquad (7)$$

If this equation is compared with equation (1), it will be seen that they can be made identical if:

$$\frac{1}{CR_1} = \frac{\triangle k}{t_0}_{max} ; \frac{a_i}{a_p CR_2} = \lambda_i ; \frac{a_s}{a_p CR_3} = 1 ; \frac{\beta}{t_0} = \frac{1}{CR_4}$$

The circuit used to solve equation (2) is shown in Fig 9b and the circuit equation is:

$$-\frac{de_0}{dt} = \frac{e_1}{CR_1} + \frac{e_0}{CR_2} \qquad (8)$$

Let $e_0 = a_i N_i$ where a_i
$e_1 = -a_p P$ a_p
} are scale factors V/unit

Then substituting in equation (8)

$$\frac{dN_i}{dt} = \frac{a_p P}{a_i CR_1} - \frac{N_i}{CR_2}$$

Comparing this equation with equation (2), they can be made identical, if

$$\frac{a_p}{a_i CR_1} = \frac{\mu_i \beta}{t_0} \text{ and } \frac{1}{CR_2} = \lambda_i$$

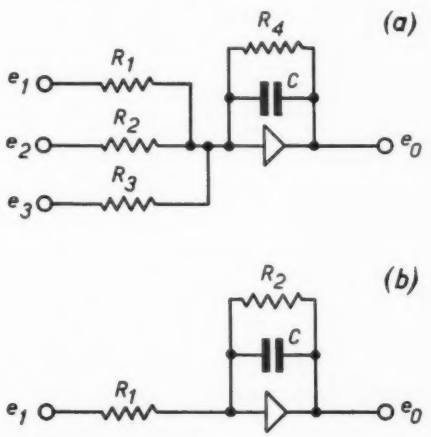

Fig 9 (a) Circuit for equation 1
(b) Circuit for equation 2

In the actual circuit, it is convenient to make $R_1 = R_2$ which gives

$$\frac{a_p}{a_i CR_2} = \frac{\mu_i \beta}{t_0} \text{ or } a_i = \frac{a_p \lambda_i t_0}{\mu_i \beta}$$

By repeating this circuit for each delayed neutron group (one 'i' for each group), and interconnecting the inputs and outputs of the circuit as shown in Fig 6 it may be seen that both equations (1) and (2) may be solved simultaneously.

ON DECRIT les premiers processus chimiques qu'on avait employé dans le programme de production militaire et l'on trace la ligne de démarcation entre les exigences fondamentales pour ce programme et celles pour le programme énergétique. On discute le traitement chimique en termes généraux et l'on souligne quelques détails de construction, caractéristiques pour les installations radioactives. On considère les applications possibles de différents processus par rapport aux facteurs techniques et économiques, tels que la composition du combustible, le degré d'irradiation, l'inventaire du combustible etc. On conclue que les installations de traitement chimique devront être, pendant quelque temps, adaptables aux différentes méthodes, puisque ni les réacteurs ni les éléments du combustible ne sont encore normalisés, et que les réactions basées sur l'extraction à l'aide des solvants vont être préférées au cours de quelques années.

ES WERDEN die früheren chemischen Prozesse des Produktionsprogramms für Militärzwecke beschrieben, und eine Grenzlinie zwischen den Grundanforderungen für dieses Programm und das Energieprogramm wird gezogen. Chemische Bearbeitung wird in allgemeinen Linien erörtert, und es werden einige Konstruktionsmerkmale hervorgehoben, die für radioaktive Installationen charakteristisch sind. Man betrachtet die möglichen Verwendungen verschiedener Prozesse in Bezug auf Technologie- und Wirtschaftsfaktoren, wie z.B. Brennstoffzusammensetzung, Bestrahlungsgrad, Brennstoffbestand usw. Man schliesst, dass es noch eine Zeitlang nötig sein wird, die Anlagen für chemische Umarbeitung anpassungsfahig zu gestalten, weil bis heute weder Reaktoren noch Brennstoffelemente genormt sind, und dass die auf Lösungsmittel-Extraktion basierenden Prozesse noch während einiger Jahre bevorzugt werden werden.

SE DESCRIBEN los primeros procedimientos químicos usados en el programa de producción para fines militares y se establece una distinción entre los requerimientos básicos de este programa y los correspondientes al de energía nuclear. El tratamiento químico es discutido a grandes rasgos y se señalan algunas características del diseño peculiares a las instalaciones radiactivas. Las posibles aplicaciones de los diversos procedimientos son estudiadas con relación a factores técnicos y económicos, tales como la composición del combustible, grado de irradiación, inventario del combustible, etc. Se llega a la conclusión de que habrá necesidad por algún tiempo de que las instalaciones elaboradoras sean adaptables, puesto que tanto los reactores como los elementos combustibles todavía no están normalizados, y que los procedimientos de extracción por disolventes serán favorecidos durante los próximos años.

ОПИСЫВАЮТСЯ первые химические процессы, употреблявшиеся в плане продукции для военных целей, и проводится линия раздела между основными требованиями военного и энергетического плана. Обсуждается в общих чертах химическая обработка и выдвигаются некоторые конструктивные признаки, характерные для радиоактивных установок. Обсуждаются возможные применения разных процессов в отношении к технологическим и экономическим факторам, как напр. состав топлива, степень облучения, наличное количество топлива и т.д. Делается вывод, что еще в продолжение некоторого времени установки химической переработки будут должны отличаться приспособляемостью, так как до сих пор ни реакторы, ни элементы топлива не нормированы, и что процессам, в которых применяется экстракция растворителем, будет отдаваться предпочтение в течение нескольких лет.

Fuel from power plants will not need high decontamination. This, however, will mean refabrication and recharging under shielded conditions

CHEMICAL

OVER FIFTY YEARS AGO, M and Mme Curie separated radium from two tons of pitchblende. The classical co-precipitation method, as used by the Curies, in which the radium was carried by barium, was still the most favoured method when the newly-discovered element plutonium was first separated from irradiated uranium by American workers during the war. This process has now been superseded by solvent extraction processes since it suffers from the following disadvantages:

1. The uranium accompanies the fission-product stream, requiring costly recovery and storage of fission products.
2. Precipitation processes do not lend themselves to remote-control, continuous operation so desirable when hundreds of tons per annum of fuel have to be processed.

In 1946 a decision was taken to build a plutonium production plant in Britain in which both the uranium and the plutonium had to be separated with a decontamination factor of about 10^5, the fission products to be in a form suitable for cheap and convenient storage.

At the time, plutonium chemistry was still in an extremely elementary state. However, by methods which were largely empirical, it was possible to give a firm recommendation in favour of solvent extraction. Two solvents were outstanding—butex (dibutyl carbitol, or dibutoxy diethylene oxide) and hexone (methyl *iso*-butyl ketone). Butex was less inflammable and was more stable to nitric acid. Thus a butex process was possible in which only nitric acid was used as salting out agent, so permitting easy concentration of the fission product waste by evaporation. This was fully described in *Primary separation at the Windscale Works* by H. G. Davey NUCLEAR POWER Vol. 1, No. 2, P. 53.

Moderate decontamination only required

When the primary function of a reactor is the production of power rather than of weapon material, the chemical treatment is radically different. Production reactors use natural uranium; they operate at comparatively low temperatures, and, in order to obtain the maximum yield of Pu-239, the irradiation time is comparatively short. Power reactors, on the other hand, range from natural uranium systems to those using pure fissionable material. Operating temperatures range from 300° C upwards, and long irradiation times with high burnup are favoured for economy. Fuel is withdrawn for chemical processing primarily to maintain its performance at some set level which may be determined by nuclear physical, metallurgical, or chemical factors. In no case is it necessary to achieve the extremely high decontamination from fission products which is attained in military production plants. A decontamination factor of 10^2 would be more than adequate for power reactors as compared with about 10^8 for existing plants. The residue of 1 per cent of the fission product activity would mean, however, that both the U and Pu would still be highly gamma-active so that all operations including the refabrication of the fuel element and its insertion in the reactor would require shielding.

The first step in chemical processing is the removal of

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PROCESSING OF NUCLEAR FUELS

by C. M. Nicholls BSc (Eng) ARIC, MIChemE
and R. Spence CB, PhD, DSc, FRIC

the fuel from its container. Decanning is usually a simple remotely-controlled mechanical operation for natural uranium but some highly enriched fuel elements generate so much heat that a heat transfer agent such as a flowing gas or liquid metal is necessary until the fuel has been dissolved or melted. The next stage involves dissolving or melting the fuel in order to release any trapped gaseous fission products and to bring about a separation from the others. If an aqueous process is to be used, the fuel is usually dissolved in nitric acid. Alternatively, it can be treated with a reagent such as bromine trifluoride to convert the U into the volatile UF_6. It is also possible to effect decontamination and plutonium separation by high temperature processes in which the fuel is melted.

Dissolution or melting of the fuel is accompanied by the evolution of gaseous and volatile fission products. The most important is Kr-85 (half life, 10.3 years) and it is common practice to allow the shorter lived rare gas fission products (mainly Xe-133; 5.3 day) and the volatile radio iodine (I-131; 8 day) to decay before processing commences. The noble gases can be safely dispersed into the atmosphere through a tall stack but even a small release of I-131 is undesirable since it is absorbed with remarkably high efficiency from the atmosphere by grass and other plants.

Conversion of fuel into liquid form, whether by dissolving or by melting, either batchwise or continuously, requires facilities for the following operations:

1. introduction of fuel into the reaction vessel
2. control of heat and addition of chemicals
3. control of the atmosphere above the fuel
4. control of temperature and pressure
5. condensation of vapours
6. removal of gases
7. removal of the liquid product

In all cases long plant life is required and reliability of operation is a necessity, so that materials of construction must be carefully selected and corrosion rates accurately known.

Phase contacting methods

Fuel is introduced by liquid seals or mechanically sealed and ventilated posting chambers, in order to prevent the escape of toxic gases. In acid dissolving, care must be taken to avoid uranium fires and in melting processes, operations must be performed under either a high vacuum or a protective blanket of a pure inert gas. Dissolving in nitric acid is usually carried out under a slightly reduced pressure so that any leakage will be inwards. When it is proposed to dissolve the uranium in bromide trifluoride, the cell must be operated under pressure in order to maintain the liquid phase while in the case of chlorine trifluoride an excess of fluorine is required in order to repress the formation of chlorine monofluoride.

The fuel having been brought into solution or liquid form, and the gaseous fission products having been disposed of, it is the aim in practically all processes to achieve the maximum possible separation from the fission products in the next stage. This usually involves phase contacting and phase separation processes such as the formation and separation of co-precipitates, contacting an aqueous phase with an organic solvent or solid absorbent and their separation, or the formation and separation of slag from a molten metal. It is highly desirable that the fission products which are separated should not be too dilute and should also be in a form suitable for easy separation of long lived constituents or for economical storage. Furthermore, the greater the degree of decontamination achieved in this stage, the less the shielding required in subsequent stages so that the character, and in many cases the cost, of the remainder of the plant is greatly dependent on the efficiency achieved here. Naturally the greatest separation efficiencies are given by multistage counter-current processes such as solvent extraction and this factor has often been dominant in deciding the choice of process.

Considerable information has been published on methods of liquid-liquid extraction (contacting and phase separation) and a wide range of equipment is available from which the plant designer can choose for his particular application.

Liquid-solid operations present considerable difficulties in highly radioactive systems largely owing to the problems involved in handling particulate solids. Ion exchange and adsorption on to solids such as silica gel have proved useful, especially in the final stages of purification. Organic ion exchangers, however, whilst often suitably selective, may not be sufficiently stable to radiation to be used in the primary separation stage. A solid-liquid phase separating technique that is showing some promise because of its simplicity is the use of miniature cyclones for removal of precipitated rare earth fission product sulphates and corrosion products from the core solution of the aqueous homogeneous reactor.

Avoidance of criticality

Whenever fissionable materials are handled in bulk the possibility always exists of a nuclear chain reaction being initiated accidentally. Vessel shapes and sizes can sometimes be designed so that the loss of neutrons from the system is so great that in no circumstances is a critical assembly possible. This restriction on plant geometry is not always acceptable and it is then necessary to rely on operational control. This may call for the limitation of the mass of fissionable material in a plant or vessel or the restriction may be on the permitted concentration. Neutron-absorbing materials would be most effective if uniformly distributed throughout the fissionable material, but this almost invariably leads to difficulties in the process. Solid fixed absorbers have been used but, without experiment, it is usually difficult to assess their value.

Perhaps the most important recent process development has been the introduction of the solvent tributyl phosphate by American workers. It is used as a solution in kerosene or similar solvent. High decontamination factors are obtained in presence of nitric acid and a salt-free fission pro-

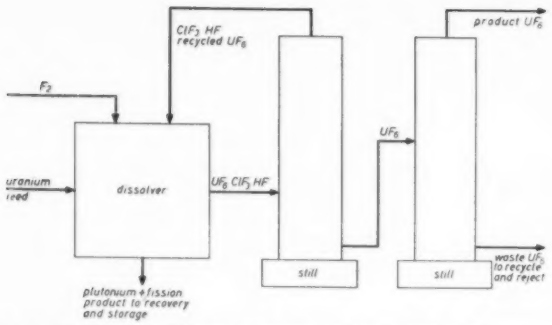


Fig 1 The chlorine trifluoride process produces high purity uranium hexafluoride

duct waste can be produced, easily concentrated by evaporation.

Methods based on the use of ion-exchangers, or chelating agents such as thiophenoyl trifluoro acetone (TTA) have been examined in many laboratories but they do not appear to offer any advantages over solvent extraction. Halogenation methods have naturally attracted considerable attention especially since fluorinating agents such as bromine trifluoride and chlorine trifluoride have become available commercially. Fluorination processes already play an important part in atomic energy operations, in the production of uranium hexafluoride for example, and there are strong arguments in favour of a fluoride separation process which can be closely integrated with an overall fluoride cycle involving diffusion plant, isotopic blending and metal production. The dissolving and phase-contacting stages of a fluorination process based on the use of chlorine trifluoride are shown diagrammatically in Fig 1. Uranium hexafluoride is produced with a decontamination factor high enough to permit it to be converted to metal in an unshielded plant. Any plutonium present in the fuel is left behind with the non-volatile fission products from which it is, in principle, separable by distillation as PuF_6 at a higher temperature.

A technically feasible method of accomplishing this has not yet been developed so that the applicability of the fluoride process is rather restricted. Its many attractive features appear to be counterbalanced, for the present, by the cost and hazardous nature of the reagents and by such problems as corrosion and criticality.

The recycling of any solid metallic fuel element usually involves a final melting of the reconstituted metal before

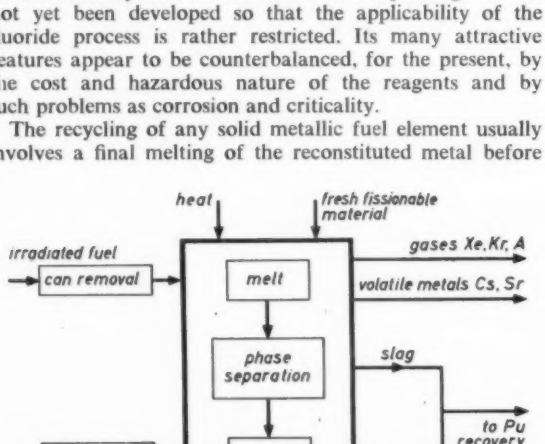


Fig 2 In a high-temperature process, most of the impurities are removed with the slag

casting, although this stage might be dispensed with if powder metallurgical techniques were used. Useful decontamination from fission products occurs during the melting of irradiated uranium metal, due to the formation of a slag by the impurities present, and this suggests a simple process in which the fuel is withdrawn from the reactor, de-canned, melted, recast, and refabricated in its can (Fig 2). Remote refabrication of the fuel would, of course, be essential and the economic attractiveness of the high temperature process would be greatly affected by the cost of this.

Processing Cost

Chemical processing is profoundly affected by the nature of the fuel cycle. Since the unit processing cost is an inverse function of the throughput, the reduction in the overall cost accompanying an increase in the irradiation time will not be so great as might at first sight be expected. This is illustrated in Fig 3 which also shows that processing costs per unit of electrical power generated tend to decrease only very slowly with increase of irradiation time beyond about 4000 MWD/t. The cost figures quoted

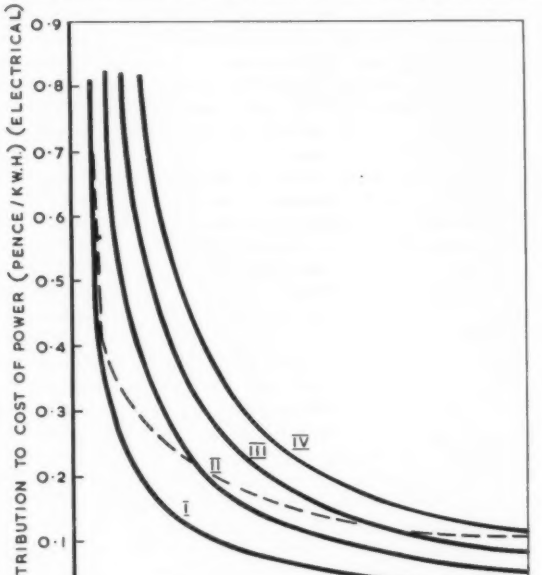


Fig 3 Curves of constant cost of processed and fabricated fuel elements in pounds sterling per ton: I—5000, II—10,000, III—15,000, IV—20,000. Dotted line shows possible cost for an actual plant

in Fig 3 are, of course, purely hypothetical, since insufficient data has so far been published concerning actual industrial plants on which to base a cost analysis.

In certain types of reactors using liquid fuel, it is proposed to separate the fission products by means of a process which is an integral part of the reactor fuel circuit. In this case, the advantages to be obtained in neutron economy from the rapid elimination of fission product poisons must be set against the higher processing cost in a small plant. Clearly only the simplest kind of operation which can easily be accommodated in the reactor ensemble will be feasible. Where a number of such reactors are grouped together at a large power station a single, more elaborate, continuous processing unit might conceivably serve them all. In this case it might also be worth while to include the blanket processing plant and any additional facilities required for periodical complete recovery of the core fluid on the same site.

This article is a shortened version of a lecture given to the Institution of Chemical Engineers in London on Feb 21, 1957

Prefabricated, free-standing glove boxes now off shelf

A pressurized cabinet, developed originally by John Bass Ltd for the assembly of B.M.B. miniature ball bearings, but having many other applications where small components have to be handled under rigorously dust-free conditions, was recently described in these pages (NP Jan 1957, p 26). By a logical extension of the idea, the firm has now introduced what is claimed to be the first completely productionized, standard glove box or dry box to be offered in the UK market. Designed not only for handling alpha- and beta-active materials, the boxes are also expected to have wide applications in the handling of dangerous pathogens and toxins, the sterile packing of antibiotics, metallurgical and other operations such as the assembly of transistors which have to be carried out in inert atmospheres.

In the pressurized cabinet, air is drawn in through a filter and passed out through the open part of the box, thus keeping the interior at a slight positive pressure. The glove box, on the other hand is completely sealed and is maintained at a negative pressure by means of a vacuum pump discharging through disposable micro-filters. Construction is of welded sheet steel and all corners are radiused to facilitate decontamination should a spillage occur. Finish is stove enamel, the exterior being 'hammered'.

Air locks may be on either side, illumination is by external striplight

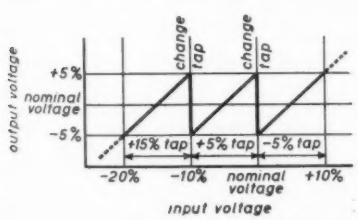
The top of the box slopes towards the operator like a desk and is largely taken up by a large plate glass window fitted to the body on a neoprene gasket. Two standard holes are fitted on the vertical front and one on each side. Normally the gloves are fitted in the front holes and the others may be used for air-lock 'post-boxes'. These are of cylindrical glass held on to the box by long bolts and fitted at both ends with quick-release doors. Neoprene washers again are provided for sealing. These dry boxes may be used singly, but they can also be used in batches with a common suction system. The dimensions of the BMB glove box are: width, 36 in. (without air lock); depth, 20 in.; height, 15 in. (back), 9 in. (front).

BMB (Sales) Ltd
Crawley, Sussex
Overseas sales:
Nuclear Research Applications Ltd,
Emefeco House,
Bell Street,
Reigate, Surrey

Automatic tap-change transformers keep voltage within 5% of nominal

Many electrical and electronic devices are inherently capable of satisfactory operation when the mains voltage varies not more than about ±5% from the "nominal" or rated input voltage value. However, when the variations exceed this amount, not only does the equipment begin to operate incorrectly, but the life of electronic components, and in particular valves, will be greatly reduced, and overheating, frequency drift, and instability will also occur.

For this reason, these devices are usually provided with input transformers or dropping resistors having a voltage selector switch or plug, giving a choice



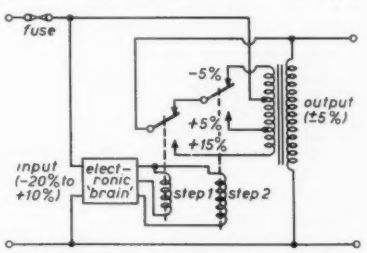
Input-output for the ATC

of three or more input settings, such as 200/210, 220/230, 240/250. This is satisfactory when the mains voltage is known and constant, and all that is necessary is to set the tap when installing the equipment, and leave it. But often the random fluctuations of the mains are large enough to require the taps to be changed during operation—which is very inconvenient at any time, and impossible with unattended equipment.

To get over this, Claude Lyons have introduced an automatic tap-changing transformer (*ATC*). This is a small, light, inexpensive and reliable electronic tap-changing transformer, so designed that the output voltage always remains within ±5% of the declared value, for input changes of as large as −20% to +10%. This range covers all likely variations in the mains voltage. The *ATC* is a development of Claude Lyons' well-known A-C Automatic Voltage Step-Regulator type ASR-1150.

The *ATC* is made in two basic sizes, rated at 2½ and 5 amperes when the voltage is 200/250. For 100/125 volt models, the current rating is double, i.e. 5 and 10 amperes. All types are available as chassis, or as convenient complete units. A range of accessory transformers greatly increases their usefulness. A fully tropicalized model is also available.

The principles of operation are simple. The transformer is provided with three output taps, and two relay-operated micro-switches select the appropriate tap to be used. The relays are operated by an electronic sensor unit, which compares a rectified sample of the input



The automatic tap-change basic circuit

voltage with a stable reference voltage produced by a miniature voltage regulator valve. The output waveform is free from distortion, and the accuracy of control is unaffected by wide variations in frequency (45/65 cycles/sec.) and fully maintained from no-load to full load. The efficiency is high, since the electronic brain only consumes about 15 watts.

Claude Lyons Ltd,
Valley Works, Ware Road, Hoddesdon, Herts

A turbine rotor on test at the General Electric Witton works

Guaranteed u/s scan for turbine shafts

An automatic method of ultrasonic testing of rotor forgings for internal faults is being investigated by the General Electric Co Ltd at its Witton works, using a Solus-Schall ultrasonic flaw detector in conjunction with a monitor.

The rotor is mounted in a lathe with the probe of the flaw detector carried in the tool rest. As the rotor is slowly revolved, the probe traverses its full length. Any internal fault causes a light to appear on the monitor and the attendant marks its position on the forging. Alternatively, provision is made for an audible warning to be given. Subsequently, any faults discovered by this preliminary scanning are explored fully by hand methods to establish their precise nature.

In addition to the outstanding advantage of a guaranteed 100 per cent coverage, the operator is relieved of the strain imposed by continuously watching a trace on a cathode ray tube, so that his efficiency is improved. Furthermore the time necessary to conduct a full examination of the forging is reduced very considerably.

A further development of this system which is now being considered, is the provision of electronic apparatus whereby the position of any fault in the rotor is marked automatically, so that it would no longer be necessary for an operator to be in constant attendance. It is expected that this would also enable the speed of scanning to be still further increased.

The General Electric Co Ltd, Magnet House, Kingsway, London, WC2
Solus-Schall Ltd, 15/18 Clipstone St, London, W1

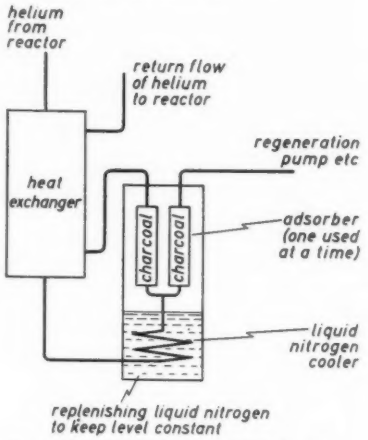
DIDO helium drying system

For the DIDO research reactor at Harwell, which uses highly enriched uranium fuel cooled and moderated by heavy water, British Oxygen Engineering Limited supplied a helium drier and adsorber to a stringent specification. If the hydrogen and oxygen resulting from radiolysis of the heavy water were allowed to accumulate, an explosive atmosphere could be produced in the reactor. To remove these unwanted gases and any possible air inleak, helium is employed in a closed circuit. This means that the helium itself has to be purified.

The problem confronting the designer was to remove completely small amounts of impurity by means of a plant of reasonably small dimensions. On the principle that the lower the temperature the greater the adsorbent capacity (resulting in a smaller volume of helium at a higher velocity in a smaller container) the method adopted has been to cool the helium down to the boiling point of liquid nitrogen (−196°C) and then to pass it over a special type of active charcoal. A great deal of experimentation, partly of the trial-and-error kind, went into finding the right type and the optimum size under operating conditions of the charcoal pieces.

The radioactive helium emerges from the reactor at around ambient temperature and is pre-cooled in an aluminium-sheathed heat-exchanger through which the purified gas is passed on its way back into the reactor.

From the heat-exchanger the helium then passes to the liquid nitrogen cooler which, together with the adsorber, is encased in a stainless steel cylinder. The adsorber is arranged in tandem for batch operation, only one section being used at a time. Periodically, the charcoal in each section in turn has to be regenerated. This is done by a combination of an increase in temperature and evacuation of the hydrogen, nitrogen and oxygen by means of a vacuum pump. In the cooler the level of the liquid nitrogen (brought to Harwell in British Oxygen insulated containers and replenished regularly) is kept constant.



Gas is cooled to −196°F in BOE dryer

Since radioactive materials are involved, the entire plant—which measures about 5ft 6 in. x 4 ft x 10 ft, must be absolutely free from risk of leaks. Hence the welding technique used in the construction had to be of the very highest quality and the plant was subjected to very stringent tests before being brought into operation. In addition, transportable leak-detectors are used regularly to ensure that the plant remains completely gas-tight. Because of the very low temperatures used, the entire plant is, of course, heavily insulated.

British Oxygen Engineering Ltd, Angel Rd, London, N18

New motors for higher temperatures

A new range of axially-ventilated squirrel cage induction motors rated from ½ to 50 h.p. was recently introduced by English Electric. These motors have standard fixing dimensions to the new British Standards draft specification CW(ELE)6246 and use Class "E" insulation which permits a temperature rise of 65°C on 40°C ambient temperature.

The new motors will supersede previous designs of ventilated machines which permitted only a 40°C rise, and are claimed to be smaller, lighter and cheaper.

The frame and end-shields are of cast iron, accurately machined to ensure concentricity and alignment. The end-shields have four-bolt fixing and can be turned to any of four 90° positions to enable floor, wall or ceiling mounting to be made.

The stator windings are automatically impregnated in a continuous plant, which immerses the windings endwise, thereby ensuring penetration of the varnish along the entire length of the slots and windings, excluding all air pockets. This process produces an efficiently protected unit which is highly resistant to moisture.

The English Electric Co Ltd, Industrial Motor and Control Gear Works, Bradford, 3

Reactor output may be increased by flux flattening. This, and the effect of control rods is discussed in NUCLEAR POWER's basic course

Reactor Physics—11

JAMES F. HILL BSc. Senior Lecturer Reactor School. Harwell

1. Critical size of a reactor running at power

The critical size of a reactor running at power can now be calculated by making allowance for the poisoning and temperature effects. The long term effects will not be taken into account.

As an example, we will take the case previously used of a cylindrical reactor and, for simplicity, assume it is surrounded by a radial reflector only. There, the height was 6·28 m, critical radius with an infinite reflector 2·62 m; 32·0 tonnes of uranium, and a radial maximum to average flux $\alpha_R = 1{\cdot}706$ (see article 8, NP Jan 1957, p.32). Other constants for the reactor are $k = 1{\cdot}06$, $L^2 = 0{\cdot}03$ m², $L^2_s = 0{\cdot}04$ m².

Suppose the average rating is 1 MW per tonne. Then from (10.6) the average flux $\bar{\phi}$ in the reactor is

$$\bar{\phi} = 2{\cdot}94 \times 10^{12} \text{ neutrons per cm}^2 \text{ per sec.} \qquad (11.1)$$

The loss in reactivity due to the equilibrium xenon poisoning is given from (9.23)*. However, it is not strictly correct to calculate the effect on k from this formula as it stands. This is because (9.23) was derived on the assumption that the flux was uniform, whereas in a reactor this is not so. In a reactor where an effect on k depends on the flux it can be shown (see Appendix) that to calculate the effect it must be weighted with the square of the neutron flux. This means in effect that a fictitious average flux has to be used different from the arithmetic average. In the case of xenon poisoning in a cylindrical reactor this fictitious average can be found by dividing the average flux by about 0·68. So then instead of (9.23) we get

$$\frac{\Delta k}{k} = \frac{-3{\cdot}045 \times 10^{-2} f}{1 + \dfrac{6{\cdot}54 \times 0{\cdot}68}{\bar{\phi} \times 10^{12}}} \qquad (11.2)$$

In the particular case this leads, if $f = 0{\cdot}87$ (which is consistent with the other constants), to

$$\Delta k = -1{\cdot}117\% \qquad (11.3)$$

The equilibrium samarium poisoning is given by (9.13), and so

$$\Delta k = -0{\cdot}700\% \qquad (11.4)$$

For the temperature effect, let us suppose the overall temperature can be taken as 250°C (this is an arbitrary figure taken simply for illustration). Then, using the figure quoted of $-2{\cdot}8 \times 10^{-5}$ in k per degree Centigrade (Article 9, NP Feb 1957, p.70), this gives

$$\Delta k = -0{\cdot}700\% \qquad (11.5)$$

Finally, adding (11.3), (11.4) and (11.5) gives

$$\Delta k = -2{\cdot}517\%$$

This then has to be subtracted from the initial k of 1·06, so

ON DEDUIT les dimensions critiques pour un réacteur cylindrique, muni seulement d'un réflecteur radial, en prenant en considération l'empoisonnement en état d'équilibre et l'effet de température. Le rendement d'un réacteur peut être augmenté si l'on "aplatit" la distribution du flux au moyen des absorbeurs au centre du noyau ; on déduit des expressions approximatives pour la distribution du flux dans un tel cas. Puis on démontre la théorie élémentaire d'une seule barre de commande et l'on introduit des corrections pour rendre raison des facteurs ignorés. On mentionne brièvement l'effet des barres multiples. Dans l'annexe on introduit le "théorème du poids statistique", qui prouve que de petits changements dans un réacteur sont proportionnels au carré du flux de neutrons dans le point en question.

KRITISCHE GRÖSSE eines zylindrischen Reaktors welcher mit nur einem radialen Reflektor ausgestattet ist, wird abgeleitet, wobei die Gleich-gewichtszustandvergiftung und der Temperatureffekt berücksichtigt werden. Die Reaktorleistung kann vergrössert werden, indem man die Flussverteilungskurve mittels der im Kernzentrum angeordneten Absorber weniger steil macht; es werden angenäherte Ausdrücke für Flussverteilung in einem solchen Falle abgeleitet. Man leitet dann die elementare Theorie des einzelnen Kontrollstabes ab und führt Verfeinerungen ein, die unbeachteten Faktoren Rechnung tragen sollen. Man erwähnt kürzlich den Einfluss mehrerer Stäbe. Im Anhang wird das "statistische Gewichtstheorem" eingeführt, welches zeigt, das kleine Veränderungen im Reaktor dem Quadrat des Neutronenflusses angegebener Stelle proportional sind.

SE DERIVA el tamaño crítico de un reactor cilíndrico con reflector radial solamente, teniendo en cuenta el envenenamiento de equilibrio y el efecto de la temperatura. La producción de un reactor puede aumentarse con el "aplanamiento" de la distribución del flujo por medio de absorbedores en el centro del núcleo, y se obtienen expresiones aproximadas para la distribución del flujo en este caso. La teoría elemental de una sola varilla de control es entonces demostrada y se introducen perfeccionamientos para explicar factores omitidos. El efecto de varillas múltiples es mencionado sucintamente. Un apéndice presenta el "teorema del peso estadístico" que demuestra que los pequeños cambios en un reactor son proporcionales a la raiz cuadrada del flujo de neutrones en el punto considerado.

ВЫВОДЯТСЯ критические размеры цилиндрического реактора с одним только радиальным отражателем, причем учитываются равновесное отравление и действие температуры. Мощность реактора можно увеличить, делая кривую распределения потока более пологой при помощи поглотителей, расположенных в центре активной зоны; выводятся приблизительные выражения для распределения потока в этом случае. Затем выводится элементарная теория для отдельного управляющего стержня, а также вводятся уточнения для учета факторов, которые не были приняты во внимание. Вкратце упоминается действие установки со многими стержнями. В приложении рассматривается «теорема статистического веса», которая доказывает, что незначительные изменения в реакторе пропорциональны квадрату нейтронного потока в данном месте.

*This formula was quoted in error. The denominator should read $-3{\cdot}045 \times 10^{-2} f$ and NOT $-0{\cdot}544 f$

that the value of k when the reactor is running at power with the poisons in equilibrium is

$$k = 1{\cdot}06 - 0{\cdot}02517 = 1{\cdot}03483 \qquad (11.6)$$

We can now proceed to repeat the calculations of critical radius (as done in ¶6 of article 8), neglecting the change in the diffusion length due to the change in f. The result of the calculations is a critical radius of 4·36 m instead of 2·62 m with a consequent increase in the uranium requirement from 32 tonnes to 88·5 tonnes for critical and so the total output is 88 MW. The maximum to average radial flux becomes $\alpha_R = 1{\cdot}647$, so that $\alpha_R \alpha_z = 2{\cdot}59$ which leads to a maximum flux of

$$\phi_{\max} = 7{\cdot}6 \times 10^{12} \text{ neutrons per cm}^2 \text{ per sec.} \qquad (11.7)$$

2. Flattening of the neutron flux

One further problem may arise in the calculation of the critical size of a reactor. This arises as follows. Consider the previous example where the maximum rating of the uranium was $\alpha_R \alpha_z = 2{\cdot}59$ MW per tonne. In an actual reactor the maximum rating determines, along with the flux distribution, the total output of the reactor. Now in order further to increase the output there are two possibilities. One is to increase the maximum rating but the other is to increase the amount of uranium in the reactor keeping the maximum rating fixed.

Now increasing the amount of uranium in the reactor will make the reactor over critical so something has to be done to keep the reactor critical with the added fuel. One method is to add absorbing rods over the central portion of the reactor in such a way that over such a region the neutron flux becomes constant or flat in the radial direction. This is called 'flattening the flux'. It has an added advantage because it also increases the radial average flux compared with the maximum so that, as well as having extra uranium, the average rating of the uranium is also increased.

Consider now the radial direction in a cylindrical reactor and let R_1 be the radius and R_0 the radius up to which the flux is to be flat (see Figure 11.1). Then, the radial flux distributions are

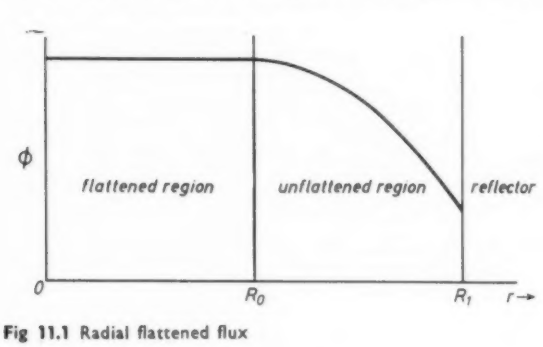


Fig 11.1 Radial flattened flux

$$\phi_0 = \text{constant} \qquad (11.8)$$

$$\phi_1 = A_1 J_0(\alpha r) + C_1 Y_0(\alpha r) \qquad (11.9)$$

where α refers to the unflattened region.

The condition at the boundary of the core and reflector will be satisfied by putting $\phi_1 = 0$ at the extrapolated value of R_1, that is, $R_1 + \Lambda_r = R_{1e}$

Then

$$\phi(R_{1e}) = 0 = A_1 J_0(\alpha R_{1e}) + C_1 Y_0(\alpha R_{1e}) \qquad (11.10)$$

Also, if ϕ_0 is constant there is no neutron current either into or out of the flattened region, so to satisfy this boundary condition

$$\left(\frac{d\phi_1}{dr}\right)_{r = R_0} = 0 = A_1 J_1(\alpha R_0) + C_1 Y_1(\alpha R_0) \qquad (11.11)$$

so combining (11.10) and (11.11) gives

$$\frac{J_0(\alpha R_{1e})}{Y_0(\alpha R_{1e})} = \frac{J_1(\alpha R_0)}{Y_1(\alpha R_0)} \qquad (11.12)$$

This then connects α, R_0 and R_1 and so given any two of them the third can be found. The important conclusion is that for a given reactor, that is, a given α, if the outer radius R_1 is picked then there is a unique value of the flattened radius R_0 for this value of R_1.

The radial maximum to average flux α_R is readily calculated from (11.8) and (11.9) using (11.10) and (11.11). For

$$\alpha_R = \frac{\int_0^{R_0} \phi_0 r dr + \int_{R_0}^{R_1} \phi_1 r dr}{\phi_0 \int_0^{R_1} r dr} \qquad (11.13)$$

so

$$\alpha_R^{-1} = \frac{R_0^2}{R_1^2} + \frac{\pi R_0}{R_1} \left\{ J_1(\alpha R_0) Y_1(\alpha R_1) - Y_1(\alpha R_0) J_1(\alpha R_1) \right\} \qquad (11.14)$$

The actual flattening may be carried out in a number of ways. Other than the use of simple absorbing rods such as steel which have been used, a neutron absorber which utilizes the neutrons may be used. Possibilities are thorium to produce U-233 or depleted uranium to produce plutonium. For these the situation soon becomes complicated because they start to produce neutrons and so alter the k in the flattened region.

It can be readily seen what has to be achieved by the flattening material to flatten the flux. From (11.8) for the radial flux to be flat, α in the flattened region must be zero and so B^2 must be equal to β^2 in this region. But because of the requirement of continuity of flux in the axial direction the value of β^2 in the two regions must be equal. So for the flattened region the value of the multiplication constant k_0 is given by

$$k_0 - 1 = \beta^2 M^2 \qquad (11.15)$$

so

$$k_0 = 1 + \beta^2 M^2 \qquad (11.16)$$

This means that absorber has to be added in such a way that the initial k is reduced from $k = 1 + B^2 M^2 = 1 + (\alpha^2 + \beta^2) M^2$ to $k_0 = 1 + \beta^2 M^2$.

In the example the critical radius at power was 4·36 m. Suppose we now want to flatten this reactor to make the core radius 5·5 m.

The value of α in the unflattened region is the same as the reactor at power. So

$$B^2 = \frac{k-1}{M^2} = \frac{0{\cdot}03483}{0{\cdot}07} m^{-2} = 0{\cdot}4976 m^{-2} \qquad (11.17)$$

$\beta^2 = 0{\cdot}25$ as before.

so

$$\alpha^2 = B^2 - \beta^2 = 0{\cdot}2476 \quad \therefore \alpha = 0{\cdot}4976 \qquad (11.18)$$

(It is not strictly correct to say that α is unchanged when going to the flattened reactor, because the flux distribution changes and so the xenon poisoning will change slightly. We shall ignore this change here.)

Then

$$R_1 = 5{\cdot}5m \quad R_{1e} = 5{\cdot}5 + 0{\cdot}455 = 5{\cdot}955m \qquad (11.19)$$

so that from (11.12) the radius of the flattened region R_0 is

$$R_0 = 2{\cdot}15m \tag{11.20}$$

and from (11.14)

$$\alpha_R = 1{\cdot}491 \tag{11.21}$$

This means that the average output in the flattened reactor is increased from 1 MW per tonne to $1{\cdot}647/1{\cdot}491 = 1{\cdot}10$ MW per tonne.

The total amount of uranium in the flattened reactor is then 141 tonnes and so the power is $141 \times 1{\cdot}10 = 156$ MW.

3. Control rods

The need for control rods in a reactor has already been discussed. We now wish to consider how the effect of an absorbing rod in a reactor can be calculated. The case we shall deal with is that of a cylindrical reactor with a control rod down the axis of the cylinder, the length of the rod being equal to the length of the core. This means that we need only deal with radial variations in the flux distribution.

The method of calculation is to consider first the critical reactor without the control rod. This gives a value for the buckling, say B_0^2, with

$$B_0^2 = \alpha_0^2 + \beta_0^2 \tag{11.22}$$

The calculation is then repeated with the control rod inserted and the value of α^2 and hence B^2 found so that the reactor remains critical at the same size. Then, because there is no change in the axial direction

$$B_0^2 = \alpha^2 + \beta_0^2 \tag{11.23}$$

then

$$\Delta B^2 = \Delta\alpha^2 \tag{11.24}$$

and on the elementary approximation that the neutrons are all thermal, as

$$B^2 = \frac{k-1}{M^2} \tag{11.25}$$

then

$$M^2 \Delta B^2 = \Delta k = M^2 \Delta\alpha^2 \tag{11.26}$$

so the change in k, Δk, produced by the rod is given as $M^2\Delta\alpha^2$. Or in other words this is the amount of reactivity which the control rod will control.

There are three sources of error in this calculation. The first is the assumption that all the neutrons are thermal and hence all neutrons in the reactor are equally likely to be absorbed by a control rod. This, however, is not the case because non-thermal neutrons are present in the reactor also and as control rods are primarily thermal neutron absorbers this calculation will overestimate the effect of a control rod. However, as will be seen later a simple correction can be made which largely does away with this objection.

The second source of error is that simple diffusion theory is inapplicable at the boundary of a heavy absorber like a control rod. In order to overcome this difficulty we shall use a boundary conditions derived from the more exact transport theory.

The third inaccuracy arises from the method of calculation. As detailed above, this supposes that the hole into which the control rod is inserted is filled with core material if the rod is not present. This will, in general, not be so as the control rod hole will be present always. As the presence of the hole means that neutrons will escape down it, this calculation leads to a further small overestimate of the effect of a control rod.

For a critical cylindrical reactor we have the usual equation (8.31)

$$\frac{J_0(\alpha_0 R)}{\alpha_0 J_1(\alpha_0 R)} = \Lambda_r \tag{11.27}$$

if R is the reactor radius.

If the reactor has a control rod of radius a inserted symmetrically along its axis, then the flux will be given by

$$\phi = AJ_0(\alpha_1 r) + CY_0(\alpha_1 r) \tag{11.28}$$

At $r = R$ we use the usual condition of (8.31) that

$$\frac{\phi}{\phi'} = -\Lambda_r \text{ where } \phi' = \frac{d\phi}{dr} \tag{11.29}$$

so that

$$AJ_0(\alpha_1 R) + CY_0(\alpha_1 R) = \Lambda_r\, \alpha_1 \left\{ AJ_1(\alpha_1 R) + CY_1(\alpha_1 R) \right\} \tag{11.30}$$

or

$$\frac{A}{C} = -\frac{Y_0(\alpha_1 R) - \Lambda_r\, \alpha_1 Y_1(\alpha_1 R)}{J_0(\alpha_1 R) - \Lambda_r\, \alpha_1 J_1(\alpha_1 R)} \tag{11.31}$$

At the surface of the control rod we introduce a similar boundary condition to (11.29), namely at $r = a$

$$\frac{\phi}{\phi'} = \Lambda \tag{11.32}$$

However, it is not possible to assign a reliable value to Λ by the use of diffusion theory, simply because the rod is black. So we use the result of a transport theory calculation

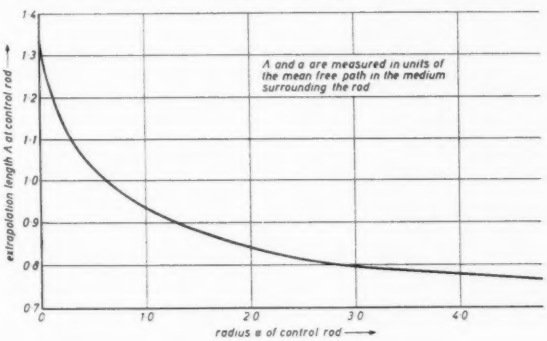


Fig 11.2 Extrapolation length at a control rod (MT214 ' Linear extrapolation length for a black sphere and black cylinder ' B. Davison and S. Kushneriuk)

which gives Λ as a function of a. This is shown in Figure 11.2. Then applying (11.32) gives

$$\frac{A}{C} = -\frac{Y_0(\alpha_1 a) + \Lambda\alpha_1 Y_1(\alpha_1 a)}{J_0(\alpha_1 a) + \Lambda\alpha_1 Y_1(\alpha_1 a)} \tag{11.33}$$

Then equating (11.31) and (11.33) gives α_1, if α_0, a, and R are known and so Δk due to the rod can be calculated by using (11.26).

In order to get a more correct result, because we are assuming that all the neutrons are thermal, we use L^2 instead of M^2 in (11.26), so that

$$\Delta k = L^2 \Delta\alpha^2 \tag{11.34}$$

This gives a much better result than (11.26).

A simple approximate result for the single rod at the centre can be obtained by using the approximate boundary conditions that

$$J_0(\alpha_1 R_e) = J_0[\alpha_1(a-\Lambda)] = 0 \tag{11.35}$$

with

$$Y_0(\alpha_1 R_e) \simeq Y_0(2{\cdot}405) \tag{11.36}$$

$$J_0[\alpha_1(a-\Lambda)] \simeq 1 \text{ as } a-\Lambda \text{ is small} \tag{11.37}$$

$$Y_0[\alpha_1(a-\Lambda)] \simeq Y_0[\alpha_0(a-\Lambda)] \text{ as } a-\Lambda \text{ is small} \tag{11.38}$$

These then lead, using (11.34) to

$$\Delta k \simeq \frac{7{\cdot}42}{R_e^2} \frac{L^2}{0{\cdot}116 + \ln[R_e/2{\cdot}405(a-\Lambda)]} \tag{11.39}$$

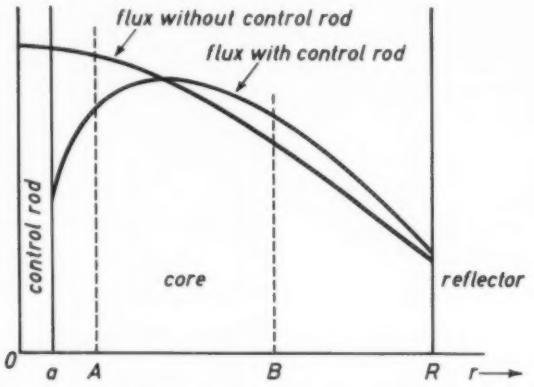


Fig 11.3 Flux distribution with and without control rod

The effect of a control rod can be seen to be due to two causes. There is the obvious one of neutron absorption but there is a further cause which makes a control rod more effective than if it were a simple absorber. This can be seen by drawing the flux distributions in the case of the reactor with and without a central control rod. If the reactor is run at the same power with the control rod in as when it is fully withdrawn then the total number of fissions must be the same in both cases and so the areas under the respective flux distributions must be equal. Inspection of Figure 11.3 then shows that the neutron current out of the core must be larger with the control rod in position and so there is an increased leakage also, in this case.

The effect of a single control rod not at the centre of the reactor can be obtained by simply saying that the effect at any radius r can be got by using the statistical weight theorem, so if $\Delta k(r)$ is this value and Δk the value at the centre

$$\Delta k(r)=\Delta k J_0^2(\alpha r) \qquad (11.40)$$

This means that the effect falls off quite rapidly with distance and so control rods are very much more effective when near the central axis of a cylindrical reactor than further out.

If more than one rod is used the total effect is not simply the sum of the separate effects of single rods. This is because the insertion of one rod distorts the flux distribution. Suppose one rod is to be placed on the axis and a further rod is to be added. Then if the second rod is put in at the position marked A in Figure 11.3 it is being inserted into a smaller flux than if the central rod were not present and so the combined effect will be less than the sum of two rods taken separately. Similarly, if the second rod is inserted at the position B, then it is being inserted into a higher flux than without the central rod and so the combined effect is greater than the sum of the two taken separately. A typical curve for Δk for N rods as a function of distance with the effect of N times one rod is shown in Figure 11.4. This shows that there is an optimum distance from the axis to put the control rods to achieve their maximum effect.

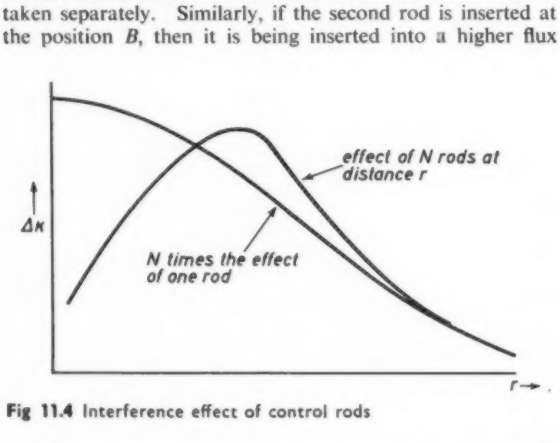


Fig 11.4 Interference effect of control rods

For a particular reactor the effect of different sized control rods at the centre can be seen by use of the approximation (11.39). If Δk is found as a function of $R_e/a-\Lambda$ for a given R_e and L^2, k increases almost linearly except for very small values of $R/_e a-\Lambda$.

APPENDIX

In a bare reactor in which the simple equation

$$\nabla^2\phi_0+B_0^2\phi_0=0 \qquad (A.11.1)$$

with

$$B_0^2=k_0-1/M^2 \qquad (A.11.2)$$

holds, if a small change is made over a volume of the reactor V_1, so that the multiplication constant there becomes k_1, then for the reactor to remain critical the multiplication constant in the rest of the reactor volume V_2 will have to be changed to some value k_2; it can be shown that

$$(k_1-k_0)\int_{V1}\phi^2dV=(k_0-k_2)\int_{V2}\phi^2dV \qquad (A.11.3)$$

the integrals being taken over the respective volumes.

This result is sometimes known as the statistical weight theorem. In effect it states that the effect of a small change in a reactor is proportional to the square of the neutron flux at the place where the change is made.

Although this result strictly applies to small changes with a consequent small change in the neutron flux, and also only to bare reactors, it is found to be valid in many cases for quite large changes and large reactors.

It is very often useful for obtaining quick solutions to problems where a very accurate answer is not required.

It can be illustrated by the use of the example above. Suppose we take the reactor at power with radius 4·36m and say 'now we wish to flatten this without changing the outside radius'. Let us make the radius of the flattened region 1m and find what value of α will be required in the unflattened region to keep the reactor critical.

Because β^2 is constant, and as we assume M^2 constant, the multiplication constants in (A.11.3) can be replaced by the appropriate values of α^2. Now we have seen above that $\alpha_0=0{\cdot}4976$ and also for the flattened region that $\alpha_1=0$. So we require to find α_2. From (A.11.3)

$$(\alpha_1^2-\alpha_0^2)\int_0^1 J_0^2(\alpha_0 r)rdr=(\alpha_0^2-\alpha_2^2)\int_1^{4\cdot36} J_0^2(\alpha_0 r)rdr \qquad (A.11.4)$$

or

$$-\alpha_0^2\int_0^1 J_0^2(\alpha_0 r)rdr=(\alpha_0^2-\alpha_2^2)\int_1^{4\cdot36} J_0^2(\alpha_0 r)rdr \qquad (A.11.5)$$

Now

$$\int J_0^2(x)dx=\frac{x^2}{2}\left[J_0^2(x)+J_1^2(x)\right] \qquad (A.11.6)$$

so the integrals in (A.11.5) are readily evaluated, leading to a value for α_2 of

$$\alpha_2=0{\cdot}529 \qquad (A.11.7)$$

This problem could also have been solved by the use of (11.12). This leads to a value of α_2 of

$$\alpha_2=0{\cdot}538 \qquad (A.11.8)$$

and so α_2 from (A.11.7) is a very good approximation to (A.11.8). even though the reactor is reflected and the flux distribution is very much distorted by the flattening.

The next article will deal with reactor kinetics

Exploration for Nuclear Raw Materials Ed. Robert D. Nininger, 6¼ in. by 9¼ in. 293 + xv pp. 60 figs. London 1956: Macmillan Price 55s.

This book is one of the Geneva Series on the peaceful uses of atomic energy, a series arising out of the ten-day Geneva Conference in August 1955. The task of assembling and correlating the material presented at this meeting on the geology and exploration of nuclear material was assigned to Mr Nininger. A great number of the papers given at the Conference have been used in the compilation of the present volume, in which all duplicated material or irrelevant matter has been omitted. The contents of those papers covering a number of different aspects have been divided and the sections inserted in their appropriate background.

The book is divided into two main parts, one section, devoted to the geology of uranium and thorium, is the smaller and contains only five chapters. The other, of 13 chapters, covers the full range of techniques used in exploration. In the geological section three of the papers are of a general nature, dealing with the occurrences and genesis of deposits and a survey of the uranium provinces, while the other two discuss factors relating to the occurrence of uranium in the United States of America. On the prospecting side all possible methods of attack are considered together with their coordination. In addition to the two principle methods of geological surveying and radiometric prospecting both from the air and from the ground, chapters deal with the supplementary geophysical methods such as resistivity and seismic surveys, geochemical prospecting, botanical prospecting and the information to be obtained from surface and ground waters. Two final chapters deal with the special problems of exploratory drilling for this type of deposit and with radioactive borehole logging.

Without doubt this is the most comprehensive book on prospecting for radioactive minerals so far published. Summarizing as it does the latest contributions from many different countries, it must also be regarded as the modern authority. One major point of interest is the remarkable similarity in the prospecting techniques developed in the different countries and the book tends to emphasize the differences where they occur. The book is well printed and substantially bound. Students wishing to obtain an overall picture of the search for uranium-thorium as well as those actively engaged in this task will find the book of great value.

J. M. Bruckshaw

Atomic Quest A. H. Compton, 5·6 in. by 8·7 in. 370 + xx pp. London 1956: Oxford University Press Price 30s.

In *Atomic Quest* Dr Compton, who was a leading figure in the American atomic bomb project until the end of the war, tells the story of this project as a personal narrative. The book is divided into five sections, *Vision, Faith, Work, Choice* and *Hope*. *Vision* describes how the American and British scientists saw the possibilities of making atomic bombs once the phenomenon of nuclear fission had been discovered; it relates how the United States Government was persuaded to start the 'Manhattan District' project because it was feared that the Germans might be the first and only nation to develop an atomic weapon. It is interesting to note that Sir John Cockcroft made the suggestion to the Americans that plutonium could possibly be made in piles and used for the manufacture of bombs.

Faith gives an account of the early work leading to the completion of the first atomic pile on December 2, 1942. Dr Compton tells us of the difficulties of providing appreciable quantities of very pure graphite and uranium. The section ends with a description of man's first controlled release of nuclear energy, and of the personal reactions to the achievement by Fermi and his collaborators.

Work outlines the building up of the vast production organizations, the gaseous diffusion plant for the separation of Uranium 235 at Oak Ridge, and the production piles for the manufacture of plutonium at Hanford. The story is told of how the fission product poison Xenon 135 almost wrecked the plutonium project; had it not been for the caution of an engineer who insisted on leaving extra holes in the piles for spare uranium if needed, the effort spent on building the piles would have been completely wasted. This section concludes with a short account of the testing of the first atomic bomb in New Mexico in July, 1945.

The remainder of the book is concerned with how the choice was made to use the atomic bomb against the Japanese, and Dr Compton's hopes for the future uses of atomic energy and the peace of the world. An account is given of some of the many discussions which took place amongst the scientists in the project on the morality of employing the bomb against Japanese cities. The reviewer, who was one of the young men who witnessed the first atomic explosion, remembers such discussions most vividly. It would not be out of place to mention that some of the younger scientists at Los Alamos, most of whom had no real conception of the horrors of war, had no qualms of conscience over the use of the bomb; however, the reviewer would certainly subscribe to the general picture of the situation as given by Dr Compton.

In the section called *Hope* the author gives his personal views on the likelihood of atomic warfare between the larger nations. This part of the book is very much coloured by Dr Compton's beliefs as a practising Christian. Many of the ideas put forward will be thought by a reader to be debatable, but all are provocative of thought and the whole section is well worthy of study.

The entire book is extremely well written and the reader requires practically no technical knowledge of nuclear energy in order to follow the story. It is a story which can be read with advantage by anyone who is interested in how a vast project is brought into being, or who is concerned with the problems posed by the existence of nuclear weapons.

D. J. Littler

The Physics of Nuclear Reactors Supplement no 5 to the British Journal of Applied Physics. London 1956: The Institute of Physics, 47 Belgrave Square, SW1

This book is a collection of the papers (complete with discussions) presented at a conference arranged by the Institute of Physics in London in July 1956. The sequence of papers is not intended to present a logical development of the physics of nuclear reactors; the subject matter has been selected with the object of drawing the attention of physicists in particular to the problems requiring solution and at the same time keeping them abreast of some recent developments.

The opening paper is by Sir John Cockcroft and deals in a general way with the physical, chemical and metallurgical problems encountered in the development of nuclear power. In attempting to deal with the future, he comes to the conclusion that "the crystal ball is never more required than in the development of atomic energy".

Two excellent summaries of the roles of Chemistry and Metallurgy in a nuclear energy project serve to give a balanced picture and place the role of physics in better perspective. Physicists and Engineers working directly or indirectly with nuclear reactors or as teachers, should find this a very interesting and valuable work.

R. Toye

And now 'Autosonics'

Every day for two weeks last month, representatives of industry, Government Departments and research associations were the guests of Kelvin & Hughes (Industrial) Ltd at their Barkingside, Essex, factory. The occasion was the introduction of K-H's new productionized range of industrial ultrasonic testing equipment which is being marketed under the trade name *Autosonics*. The event marked another stage in the process which has steadily brought the firm into a leading rôle in this field. As far back as 1943 K-H produced the first commercial equipment for ultrasonic inspection and this was used with great success on armour plate and airplane spars. Subsequent developments, said Mr G. B. G. Potter, a K-H director, had brought the technique into a fully proved method of non-destructive testing, the only drawback being its slowness for mass production applications. *Autosonics* removes this by making this form of inspection fully automatic.

By the use of automatic traversing and scanning devices it is possible rapidly to inspect a complete unit using a system fully protected against all system faults. Visitors to the demonstration were able to see a 10 in. dia aluminium billet and a large 1 in. steel plate being inspected in this way, a complete record of the inspection being plotted on a chart recorder. Other applications showed weld inspections done completely automatically. The *Autosonics* range includes a variety of productionized equipment to suit special purposes, all equipment being built round standard units.

Speaking at a luncheon, one of Kelvin-Hughes' directors, Air Chief Marshal Sir John Boothman, said he was confident that in *Autosonics* his company had an article that was ahead of its German and American competitors.

New company to make 'Flostats'

The formation was announced last month of a new company, G. A. Platon Ltd, to provide a technical sales service for industries concerned with fluid handling. This ranges from the stockholding of established plant items in general demand, such as flowmeters, flow-controllers and pumps, to the development and introduction of new devices, particularly in the field of automatic control. The company has acquired from the patentees and Ultrasonics Ltd exclusive rights to manufacture and sell the *Flostat* automatic flow controller.

Mr G. A. Platon, who is one of the directors, was technical sales manager of the Rotameter Manufacturing Co Ltd for many years. The other directors are Dr Mitchell, a chemical engineer with experience of nuclear engineering problems gained at Harwell and Aldermaston, and Mr F. J. Minett, experienced in precision machining for the instrument industry. Address: 323A Whitehorse Road, Croydon, Surrey.

Reading by Electronics

The Solartron Electronic Reading Automaton (ERA), which enables computers to read and recognize ordinary printed material, was recently demonstrated at Solartron's research centre, Goodwyn's Place, Dorking. Said to be the first electronic reading machine in the world to be shown in the production pilot stage, the ERA is capable of reading characters at the rate of 120 per second. Fully productionized machines will read up to 500 per second. It is claimed that it may be tailored to suit the requirements of all types of computing devices, office machinery and the needs of administrative organization in every industry.

New irradiation service soon

A commercial irradiation service will shortly be available at the Barton Works of Metropolitan-Vickers Electrical Co Ltd where a 4MeV linear accelerator is being built in a special laboratory. When it is complete, firms will be able to buy machine time in order to study irradiation effects on their materials and even to carry out manufacturing processes. A somewhat similar 4MeV linear accelerator with a power of 1·5kW was recently supplied to the AERE radiation laboratories at Wantage.

MERLIN Control drives from MV

Complete control systems are in hand at Metropolitan-Vickers for the three MERLIN light-water-moderated research reactors being supplied by AEI-John Thompson to the Atomic Weapons Research Establishment, the AEI Research Laboratories and Federal Germany. Each reactor is provided with four actuating mechanisms, two for the safety rods and one each for the coarse and fine control rods. Three-phase induction motors drive the safety and coarse control rods, while the fine control rod is driven by a d.c. servo motor. Each motor drives through reduction gearing to a rack and pinion, the rack being coupled to the rod by an electromagnetic clutch which can be de-energized to drop the rod and provide fast shut-down under emergency conditions. The fine control rod is operated automatically by a closed loop servo system. A signal proportional to power error is fed into a valve-controlled magnetic amplifier which controls the servo motor. The control and display instrumentation for the three reactors has been ordered from Sunvic Controls Ltd.

AEI-John Thompson are also supplying AERE Harwell with the first 50MeV section of a proton accelerator and a 25MeV electron accelerator. The former is nearing completion and has involved connecting up four thousand power and control wires at voltage varying from 18kV to 50kV.

NP will be at Olympia

NUCLEAR POWER will have a stand at the *Instruments, Electronics and Automation Exhibition* (Olympia, London, May 7 to 17). Two hundred British manufacturers will be taking part, and the exhibition is backed by five leading trade associations. Among the exhibits will be a wide range of computers for scientific, industrial and commercial uses, industrial and closed-circuit television and nucleonic equipment. A conference at which techniques and applications will be discussed by experts in the field, among them Sir Claude Gibb, will form an integral part of the exhibition.

NUCLEAR POWER will be at stand 102A and we shall be glad to meet readers and advertisers there at any time during the exhibition.

Mr H. G. Nelson, English Electric Ltd managing director (l), with the manager of EE's industrial motor division, Mr C. Horne, inspect some of the company's new range of ventilated motors.
(See Equipment story p 156)

Sunvic computer for Navy

A resistance analogue network recently completed by Sunvic Controls Ltd at their Harlow, Essex, factory for the Admiralty was shown on Feb 28 at Imperial College, London, where it has been installed. The host on this occasion was Prof O. A. Saunders and distinguished guests included Rear Admiral G. A. Wilson who is now in charge of nuclear propulsion at the Admiralty.

The purpose of the computer is primarily to solve problems in connexion with the heat flow into steam or gas tur-

At the unveiling of the computer, a group inspect the print-out typewriter. (l to r) N. R. Davis, Sunvic managing director; C. C. Hall, Sunvic design dept; S. Bolshaw, Deputy Director (Engineering), R.N. Scientific Service; Dr R. D. Hoyle, Imperial College

bine shafts under transient conditions but it can also be used for other problems using the same type of differential equation; such equations occur in problems of diffusion and mass-flow. The computer is based on a manually operated apparatus developed by the late Dr Leibmann of the AEI Research Laboratory.

In this method, electrical networks represent the finite difference equations which replace the differential equations governing the problems to be solved. Temperature is represented by voltage, the spatial features of the problem by a network of parallel resistances, and the thermal constants by these and series resistances. A solution in discrete intervals of time is obtained by successive readjustments of potentiometers supplying the voltage to the network. This method, similar in character to certain numerical methods though much faster, is very flexible, the thermal constants being adjustable during the progress of the work.

Teachers see Elliott computers

Twenty senior staff members from higher technical colleges all over Great Britain recently visited the Borehamwood works of Elliott Brothers where they saw some of the latest developments in electronic analogue computing techniques demonstrated on a number of the company's general purpose analogue computers.

The visitors were welcomed by Commander H. Pasley-Tyler, manager of the Elliott Borehamwood Group and, before seeing the computers in action, heard a series of short lectures which were opened by Mr A. D. Jeffery, chief engineer, analogue computing. He said in his experience of lecturing at technical colleges, and in his contacts with many branches of industry, students and engineers did not appear to have appreciated fully the great contribution analogue computing machines could make to solving many present-day problems. He hoped that, by coming to Borehamwood, his visitors would have become more familiar with the techniques and possibilities involved.

Among the problems later simulated on the Elliott machines was one concerning the development of power in a nuclear reactor. Another dealt with control of re-heat in a jet engine.

DuPont Durapipe

In our notice 'Plumbing with a paint brush' (NP March p109) we incorrectly described the range of plastic pipes manufactured by Richard E. DuPont Ltd as being made of polythene. There are actually three different kinds of Durapipe, viz: *Durapipe Z*—Ziegler polyethylene, *Durapipe K*—Butadiene styrene acrylonitrile blend, *Durapipe N*—Nylon 6. Only types K and N are suitable for solvent weld jointing: type Z is jointed by heat blending as described in our second paragraph. The manufacturers state that this notice in NUCLEAR POWER has already created considerable interest in this piping.

Signals Officers visit Racal

A group of senior signals officers from the Air Ministry, Royal Air Force, and the Ministry of Supply recently paid a visit to the Bracknell, Berkshire works of Racal Engineering Limited where they inspected the latest developments in certain important defence projects on which the company is engaged.

They were conducted on a tour of the factory by Mr R. F. Brown, Mr G. C. Cunningham and Mr M. I. Forsyth-Grant, directors of the Company and were shown the new Racal HF Communications Receiver RA.17 being assembled in the main production shops. In the research and development laboratories they also examined the range of digital counting equipments, some items of which are being incorporated in a high precision timing installation which has been specially designed for the National Physical Laboratory.

Racal director R. F. Brown discusses a point with Air Marshal R. G. Hart, Brigadier J. D. Haigh and Brigadier W. Scott

French buy British knowhow

20th Century Electronics Ltd has signed a new 5-year agreement with the French Compagnie Général de Télégraphie Sans Fil, under which the French organization will use 20th Century's designs and patents. Provision is made in the agreement for the training of French engineers and the exchange of 'know-how.'

This was announced last month by 20th Century's Gilbert A. R. Tomes on his return from Europe where he had also been negotiating the sale of a licence for the manufacture of boron isotopes (see NP Nov 1956, p. 304).

CGTSF is one of the largest and most important electronic tube manufacturers in Europe, covering the whole field of telecommunications. Amount paid for the renewal of the licence was not disclosed, but it is understood to be substantial.

Over the past seven years 20th Century has signed similar licence agreements with the Netherlands, Belgium, Germany, Switzerland, and France. Prime interest of the firms who buy these licences is to make geiger tubes and multi-gun cathode ray tubes.

Cape 'Rocksil'

Last month's *Companies* reported that *Rocksil* mineral wool manufactured by the Cape Asbestos Company is being used at Dounreay on the fast breeder reactor. William Kenyon & Sons Ltd, Dukinfield, now inform us that they are the thermal insulation contractors for the project, through John Thompson Ltd,

for the AEA. Kenyons have designed a special system of reinforcement, suspension and finish, using Cape *Rocksil*, based on an exclusive system used by the company for many years.

200 miles of tubing from TI

Contracts for over 200 miles of tubing, mainly of austenitic stainless steel, have been received by the Tube Investments subsidiary, Accles & Pollock Limited, Oldbury, Birmingham, from AEI-John Thompson Nuclear Energy Co Ltd, and the GEC Simon-Carves Atomic Energy Group for their nuclear power stations in Gloucestershire and on the Ayrshire coast. Some of the tubes will be supplied in straight lengths and others manipulated and part fabricated.

In Brief

BIRLEC LTD are showing scale models of arc melting furnaces at the German Industries Fair, Hanover (see *Worldview*, this issue).

PHILIPS ELECTRICAL LTD have set up a new South-Western Regional Headquarters at 1 Gerrard Place, London, W1 (tel: Gerrard 9941; grams: Philsales Lesquare London).

BAILEY METERS & CONTROLS LTD have moved their main Project and Estimating Section to the new plant at Croydon. Correspondence previously addressed to 153 Moorgate, London, EC2, should now go to: Bailey Meters & Controls Ltd, Sales Dept, Purley Way, Croydon, Surrey (tel: Croydon 4191).

NAMES IN THE NEWS

Mr G. R. Peterson has been appointed Deputy Chief Engineer (Generation and System Operation) of the Central Electricity Authority. Mr Peterson was previously Generation Operation Engineer.

Mr J. L. Thomas has rejoined The Cape Asbestos Co Ltd as Scottish Area Branch Manager at Glasgow. He replaces **Mr D. A. Lambert.**

The Plessey Co Ltd have appointed **Mr F. C. Loughborough** as executive assistant (sales) to **Mr John A. Clark** who is group director.

The Rt Hon The Lord Clitheroe has been appointed a director of Tube Investments Ltd.

Mr R. Turner, chief engineer of Powell Duffryn Technical Services Ltd has been appointed to the board of that company. He replaces the chief engineer of Powell Duffryn Ltd, **Mr G. W. Alexander.**

The General Electric Co Ltd have appointed the **Rt Hon A. R. W. Low,** PC, CBE, DSO, TD, MP, as a director. Mr Low who is a director of Grindlay's Bank, has represented Blackpool North in Parliament since 1945 and was Parliamentary Secretary to the Ministry of Supply from 1951 to 1954 and Minister of State, Board of Trade, from 1954 to 1957.

Mr A. O. Ahlquist has been appointed assistant sales manager, mechanical department of Metropolitan-Vickers Electrical Co Ltd. He has been with MetVic since 1941.

Metropolitan-Vickers Electrical Co Ltd have appointed **Mr N. J. Austin** as assistant to sales manager, mechanical department.

Mr M. Emori, previously London manager of Mitsubishi Shoji Kaisha Ltd, has gone to Tokyo to take charge of the produce department. He is succeeded in London by **Mr N. Nakamura.**

Mr R. D. Phillips recently rejoined 20th Century Electronics Ltd as senior engineer in charge of cathode ray tube pre-production. He will be responsible for prototype development and production engineering.

Vickers Ltd announce the following additions to their board of directors: **Mr E. O. Faulkner,** MBE, and **Mr G. H. Houlden.**

As from last December **Mr L. G. Piggott** becomes sales manager of Alfred Imhof Ltd. Mr Piggott was previously in the service division.

The following changes have been made to the board of directors of Griffin & George Ltd. **Mr Ronald McKinnon Wood,** OBE, has resigned as chairman in view of his duties as chairman of the LCC. He is succeeded for the time being by **Mr H. R. Bettinson,** MC. **Mr Norman McKinnon Wood** replaces Mr Bettinson as vice-chairman and **Mr Norman Trepte** steps into the managing directorship.

Mr William Bryson, General Manager of Motherwell Bridge and Engineering Co Ltd, is to retire in July. He joined the Company as far back as 1912 as a junior draughtsman and the Directors have paid tribute to his incalulable service during his years with company. He is to be succeeded by Chief Designer **James McLean** BSc, ARIC, who in the interim has been made Joint General Manager.

Mr J. I. Bernard has been appointed Director and Secretary of the British Electrical Development Association in succession to **Mr V. W. Dale** who is resigning on health grounds. Mr Bernard joined the EDA in 1928 and has been chief technical officer since 1936. He has written numerous articles and books on the use of electricity for industrial purposes, particularly process heating, and was closely connected with the establishment of the EDA testing house.

Lt-Cmdr R. B. Lakin, DSO, DSC, has been appointed managing director of George Mann & Co Ltd.

Mr Victor Thomas who has been in charge of the Fielden Electronics home sales for the past twelve months has now become responsible also for the organization of export sales.

Mr A. P. Wickens has been appointed managing director of Vickers-Armstrongs (Tractors) Ltd and ceases to be a director of Vickers-Armstrongs (Engineers) Ltd and general manager of Elswick, Scotswood and Wakefield works.

Honeywell-Brown Ltd have promoted **Mr W. R. Owen,** previously manager of their Sheffield branch office, to manager for the North East region. Mr Owen will be succeeded at Sheffield by his former deputy, **Mr A. Hague.** The company have also appointed **Mr Halstead** and Mr **Gabe** to manage their Middlesbrough and Cardiff offices respectively.

It was announced by Johnson, Matthey & Co Ltd last month that **Mr H. W. P. Matthey,** the company's chairman, had died at the age of eighty. Mr Matthey joined the company in 1894, became a director four years later and chairman in 1928.

INSTITUTIONS

Nuclear Metallurgy

A vacation course on this subject will be held at Battersea Polytechnic, London, from April 9–12 inc. A distinguished group of lecturers has been obtained for the course and includes: Prof J. G. Ball, W. D. Jamrack, H. Lloyd, M. B. Waldron, L. Grainger, J. A. L. Robertson, A. B. McIntosh, J. N. Wanklyn, L. M. Wyatt and B. R. T. Trost. Lectures will be from 10–5.15. Full details from the Secretary.

Physics conference fixed for July

The AGM of the Physical Society will be held on Tuesday, June 4, at 4.45 p.m. at the Science Museum, London, SW7, when Prof N. F. Mott will deliver his presidential address. The society's next nuclear physics conference will be held in the physics department of Manchester University and will be organized by Prof S. Devons, FRS. It will be a two-day meeting to take place some time during the period July 15–20.

A conference on *Physics of the Solid State* organized by the Society will be held at Nottingham University on April 8–10.

Post graduate course

Imperial College, London, is offering a one-year post-graduate course in nuclear power under the direction of Prof J. M. Kay. It will be open to holders of a good honours degree in any branch of engineering. The syllabus comprises basic nuclear physics, reactor theory, fuel technology, radiation, design of power reactors. Optional lectures will cover more specialized aspects. Lecturers will include Professors J. G. Ball (Physical Metallurgy), P. M. S. Blackett (Physics), P. V. Danckwerts (Chemical Engineering), D. M. Newitt (Chemical Engineering), O. A. Saunders (Mechanical Engineering) and A. Tustin (Electrical Engineering). The course starts in October.

Chem. Eng. Symposium

The Graduates' and Students' section of the Institution of Chemical Engineers will be holding a symposium on *The impact of atomic energy on chemical engineering* at the Cora Hotel, Upper Woburn Place on April 26. The following papers will be presented: *Solvent extraction* by J. M. Fletcher, Head of Chemical Processing Group, AERE, *The chemical processing of nuclear fuels* by B. F. Warner, Research Manager, Windscale, *Ion-exchange applications in atomic energy* by L. D. Roland, Senior Chemical Engineer, Permutit Co, and *Industrial utilization of irradiation* by R. Roberts, Technological Irradiation Group, AERE, Harwell. The chair will be taken at the morning session by Prof J. M. Kay, Imperial College and in the afternoon by A. S. White, Head of Chemical Engineering Division, AERE. The discussion will be opened by Prof P. V. Danckwerts, Imperial College. There will also be a film *Steel and atomic energy*, produced by BISRA. Applications for the symposium should be made by April 17.

PUBLICATIONS

Aiminal Aluminium Alloys for Extrusions, Tubes and Forgings. A catalogue of physical properties and dimensions of a wide range of sections produced by Southern Forge Ltd, Meadfield Rd, Langley, Bucks.

PV=RT An attractive brochure forming a concise guide to industrial vacuum plant, it illustrates the wide range of equipment manufactured by W. B. Heraeus GmbH, Hanau, W. Germany. Of interest to nuclear technology is the range of high vacuum furnaces. British agents: Fleischmann (London) Ltd, 19 Northumberland Avenue, London WC2.

The Technical Journal of the Brush Group—Spring 1957 containing a useful article on Cast Resins by A. B. Cameron. The Brush Group Ltd, Duke's Court, Duke St, London SW1.

Braun Heat Exchangers A booklet describing the heat exchangers designed by C. F. Braun & Co, Alhambra, Cal. which are now made under licence by Ashmore, Benson, Pease & Co Ltd, Stockton on Tees, Co. Durham.

Ketay Precision Components Describes a new range of high accuracy miniature servo-mechanisms comprising synchro transmitters, receivers, resolvers, tachometer-generators and induction motors—all to NATO standards. Ketay Ltd, Eddes House, Eastern Avenue, W. Romford, Essex.

Power through nuclear energy NOW A booklet detailing the agreement for power reactors concluded last year between AMF Atomics of New York and Mitchell Engineering of London. It also describes the AMF closed cycle boiling water reactor which is being built at Elk River, Minn. Mitchell Engineering Ltd, 1 Bedford Sq, London WC1.

Civil Engineering—a creative career A leaflet from the Institution of Civil Engineers explaining for schoolboys four ways of becoming a Chartered Civil Engineer. ICE Gt. George St, London SW1.

Muirhead & Co Ltd, Beckenham, Kent, have issued a technical leaflet (9751-A) describing the D-729B Low frequency phasemeter.

The Journal of Applied Pneumatics Vol 2 No 14 illustrates industrial uses of pneumatic power. 1s. 6d. from Martonair Ltd, Parkshot, Richmond, Surrey.

The Fisholow Magazine Vol 3 No 15 contains several articles on aspects of mechanical handling. Fisher & Ludlow Ltd, Bordesley Works, Birmingham, 12.

Expandite Ltd, Chase Rd, London NW10 have issued a leaflet describing their RB 200 preformed rubber/bitumen extruded sections for sealing against water or gas.

The CAC Magazine Vol 6 No 1 includes a description of how 'Caposite' was used in stress relieving the welded joints in the Calder Hall heat exchangers. Cape Asbestos Ltd, 114-116 Park St, London W1.

Metropolitan Vickers Gazette Vol 28 No 450 contains its customary annual review of activities and a colour frontispiece of part of the wave-guide of the 25 MeV electron linear accelerator supplied to Harwell.

Airmec Ltd have issued a comprehensive catalogue in a loose-leaf folder of their electronic instruments. Airmec Ltd, High Wycombe, Bucks.

RESEARCH REPORTS

United Kingdom

*The following reports have been made available to the public by the United Kingdom Atomic Energy Authority. They may be borrowed or photocopies obtained from the Science Library, London, Department of Industrial and Forensic Science, Belfast, the Mitchell Library, Glasgow, and the Central Libraries at Ashton, Birmingham, Bristol, Kingston-upon-Hull, Leeds, Liverpool, Manchester, Newcastle-upon-Tyne and Sheffield. They are also deposited in the Copyright Libraries (i.e. British Museum; University Library, Cambridge; Radcliffe Science Library, Oxford; National Library of Scotland, Edinburgh; National Library of Wales, Aberystwyth) and in the Patent Office Library. Reports marked * may be purchased from Her Majesty's Stationery Office.*

Reports are also available in the United States, from the USAEC depository libraries, a list of which will be found in NUCLEAR SCIENCE ABSTRACTS. Reports for sale may be purchased in the United States from: Sales Section, British Information Services, 30 Rockefeller Plaza, New York 20, N.Y.

AERE Harwell

The absorption of inorganic salts by non-ionic resins. (A new absorptive mechanism). *J. Kennedy, H. Small.* (Nov, 1955. 13 pp) 2s. 3d. AERE-C/R 1668*

Separation of heavy metals with acid alkyl phosphate and phosphonate resins. *J. Kennedy, R. V. Davies, B. K. Robinson.* (Mar 3, 1956. 6 pp) 1s. 3d. AERE C/R 1896*

An experimental study of neutron induced activities in water. *N. Faull.* (May, 1956. 42 pp) 5s. 9d. AERE R/R 1919*

Coupling of resonant cavities by resonant coupling devices. *P. D. Dunn, C. S. Sabel, D. J. Thompson.* (Dec, 1956. 46 pp) 6s. 3d. AERE GP/R 1966*

Radiation from gases. *W. R. Hindmarsh* (Aug 28, 1956. 33 pp) AERE GP/R 2028

On the ion adsorption properties of synthetic magnetite. *P. J. Anderson.* (Sept 8, 1956. 29 pp) AERE M/R 2046

Bibliography on shock waves, shock tubes and allied topics. *K. Dolder, R. Hide.* (Sept, 1956. 100 pp) 13s. AERE G/R 2055*

Spiral ridge cyclotrons with frequency modulation. *L. B. Mullett.* (Oct, 1956. 21 pp) 3s. 3d. AERE GP/R 2069*

A note on the potential of plutonium amalgam electrodes. *A. G. White.* (Nov, 1956. 13 pp) 2s. 3d. AERE C/R 2099*

An impurity analysis of aluminium by radioactivation and scintillation spectrometry. *P. Iredale* (Oct, 1956. 15 pp) 2s. 6d. AERE EL/M 96

The measurement of fast neutron flux for irradiation damage studies. *D. G. Martin.* (Nov 20, 1956. 6 pp) AERE M/M 138

Longitudinally polarized beta particle emission as a consequence of the failure of parity conservation in beta decay. *P. E. Cavanagh, C. E. Coleman.* (1957. 2 pp) AERE N/M 80

Selected abstracts on the use of organic materials as moderator-coolants of reactors. *G. Naish, R. W. Bowring.* (Aug 1956. 11 pp) 2s. AERE Inf/Bib 105*

Purification of graphite. *P. M. Harris.* (Oct, 1956. 8 pp) 1s. 6d. AERE Inf/Bib 109*

Sources of information in atomic energy. *L. J. Anthony* (Nov 23, 1956. 18 pp) AERE Lib/L 1

Industrial Group

Determination of the plutonium content of urine (phosphate method). Revised edn. (Jan 9, 1957. 6 pp) IGO-AM/W 68

An investigation into the incidence and distribution of foot injuries at Capenhurst Works. *R. E. Dewhirst, F. Morley.* (Dec, 1956. 7 pp) IGO-R/CA 46

Factors affecting the distance of the discharge point from the shore in the sea disposal of effluent. *A. E. Shaw.* (Feb, 1957. 11 pp) IGR-TN/D 443

The Windscale air-flow rig for heat transfer measurements. *A. Atherton, G. Horn.* (Feb 1957, 13 pp) IGR-TN/W 453

Liquid vapour equilibria in the system chlorine trifluoride-hydrogen fluoride. *J. F. Ellis, C. W. Forest.* (Feb, 1957. 5 pp) IGR-TN/CA 457

PROGRAMME

ICE Institution of Civil Engineers. IMechE Institution of Mechanical Engineers. IEE Institution of Electrical Engineers. IChemE Institution of Chemical Engineers. IP Institute of Physics. PS Physical Society. SCI Society of Chemical Industry. IM Institute of Metals. IMet Institution of Metallurgists. IMM Institution of Mining and Metallurgy. IPE Incorporated Plant Engineers. SIT Society of Instrument Technology.

APRIL

TUESDAY 2

LONDON IChemE (BNEC) The aqueous homogeneous reactor *R. Hurst* 5.30 at Royal Institution

EDINBURGH IPE The generation and use of steam—film show. 7.00 at Heriot-Watt College

NEWCASTLE IEE Faraday lecture: Nuclear energy in the service of man *T. E. Allibone FRS* Tickets: R. Bruce, C. A. Parsons & Co Ltd, Heaton Works, Newcastle, 6

LOUGHBOROUGH IEE Power amplifiers used in automatic control *J. V. Parry* 6.30 at the College

WEDNESDAY 3

NEWPORT IMechE Nuclear Power: basic principles and their application *Professor J. Diamond*

THURSDAY 4

LEICESTER IMechE Nuclear Power: basic principles and their application *Professor J. Diamond* College of Technology and Commerce, 7.15

TUESDAY 9

MANCHESTER IEE Faraday lecture (see April 2) 7.00 at Free Trade Hall

BIRMINGHAM IChemE Symposium on chemical engineering education At Chemical Engineering Dept, The University, Edgbaston. Continues to 10th and 11th

BELFAST IEE Age and incidence of fires in electrical installations *L. Gosland* 6.30 at Engineering Dept, Queens University

WEDNESDAY 10

BIRMINGHAM IMechE Irradiation of materials *A. Charlesby and W. H. Davieson* 6.45 James Watt Memorial Institute, Great Charles Street

GLASGOW IMechE Informal lecture on nuclear energy *A. T. Bowden* 7.30, Institution of Engineers and Shipbuilders in Scotland, 39 Elmbank Crescent

ABERDEEN IEE Nuclear reactors and power supply *G. W. K. Ford* Robert Gordon's Technical College

LIVERPOOL IEE Faraday lecture (see April 2) At the Philharmonic Hall

THURSDAY 11

GLASGOW IPE Applications of photography in industry *A. Horder* 7.15 at Scottish Building Centre, 425 Sauchiehall Street

LIVERPOOL IPE Engineering in the making of refractories *E. Snodgrass* 7.15 at Exchange Hotel

DUNDEE IEE Nuclear reactors and power supply *G. W. K. Ford* 7.00 at Queen's College

TUESDAY 16

LONDON IMechE Pneumatic controllers for process control *K. S. Jones* 6.30 at the Institution

WEDNESDAY 17

ROCHESTER IPE The plant engineer and work study *H. A. Gomm* 7.00 at King's Head Hotel

WEDNESDAY 24

LONDON SIT Measurement and control circuits in the human operator *W. K. Taylor* 7.00 at Manson House, Portland Place, W1

THURSDAY 25

SHEFFIELD IPE Welding applied to maintenance *A. O'Donnell* 7.30 at Grand Hotel

TUESDAY 30

LONDON SIT The preparation and industrial application of diffraction gratings *L. A. Sayce* 7.00 at Manson House, Portland Place, W1

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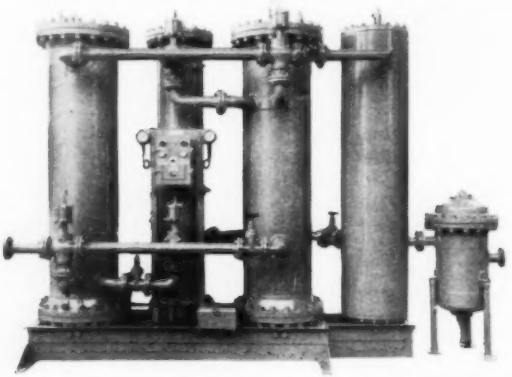

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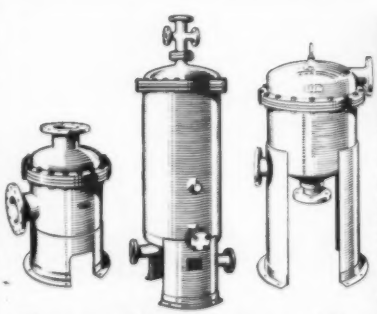

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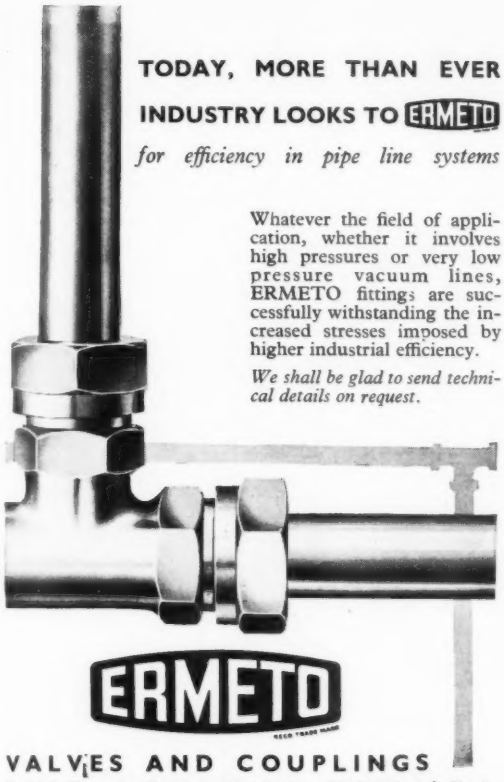

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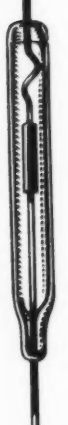

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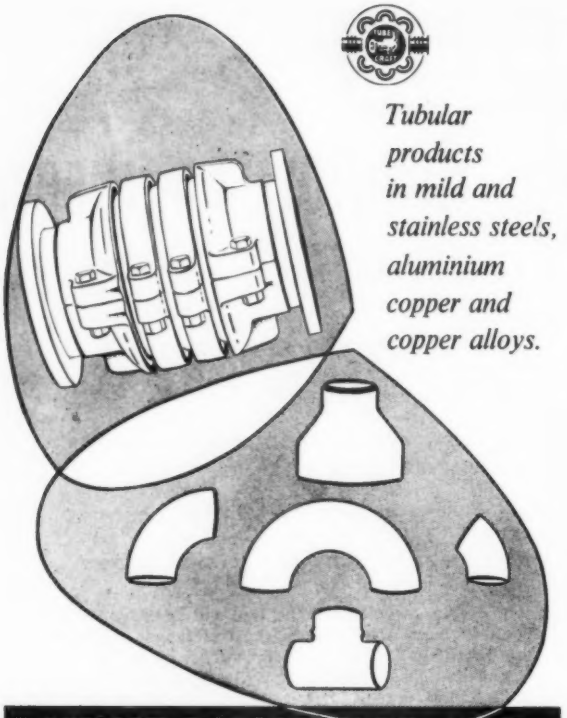

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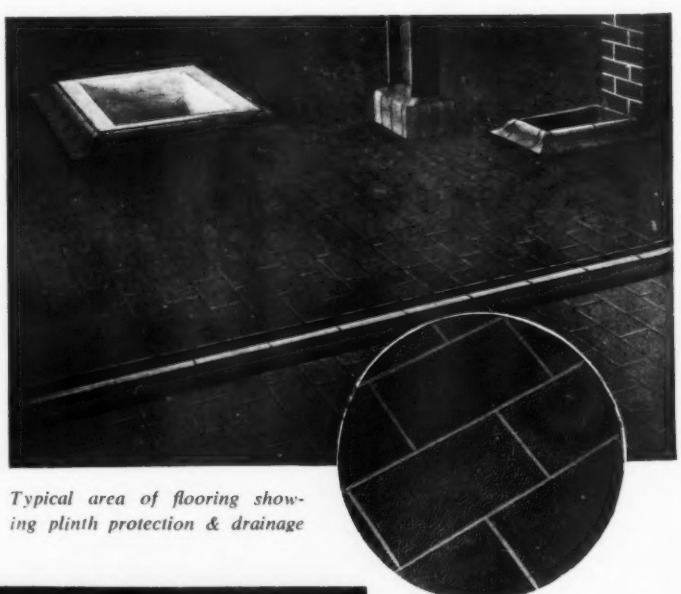

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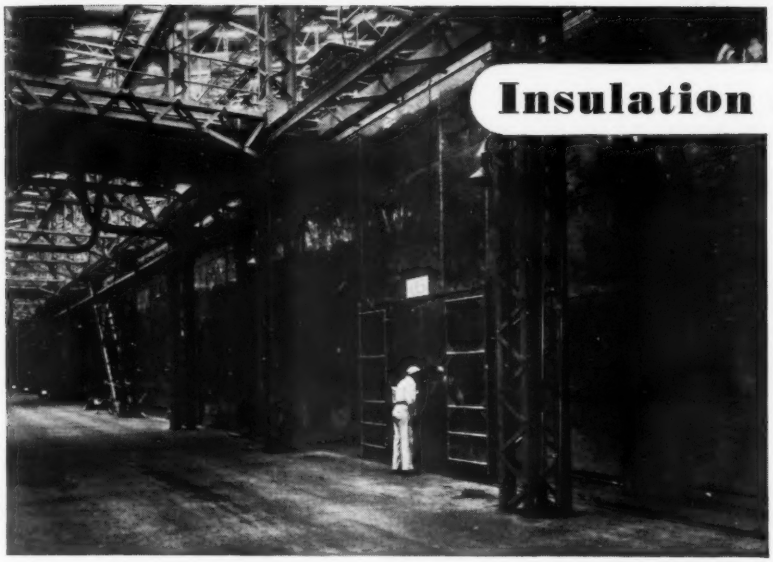

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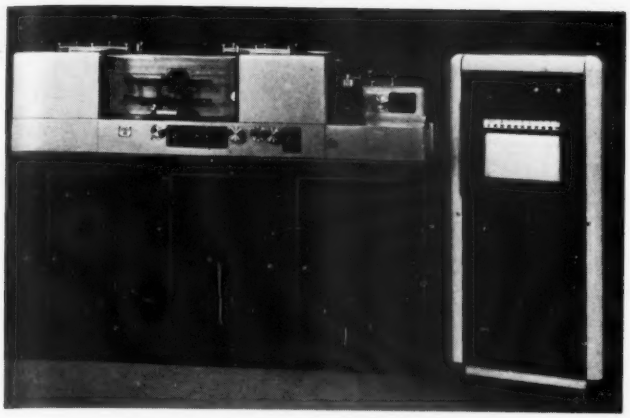

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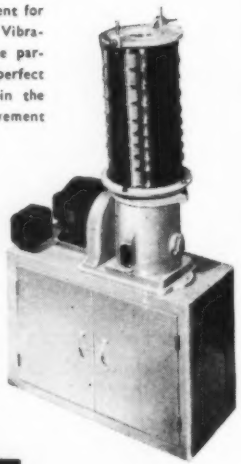

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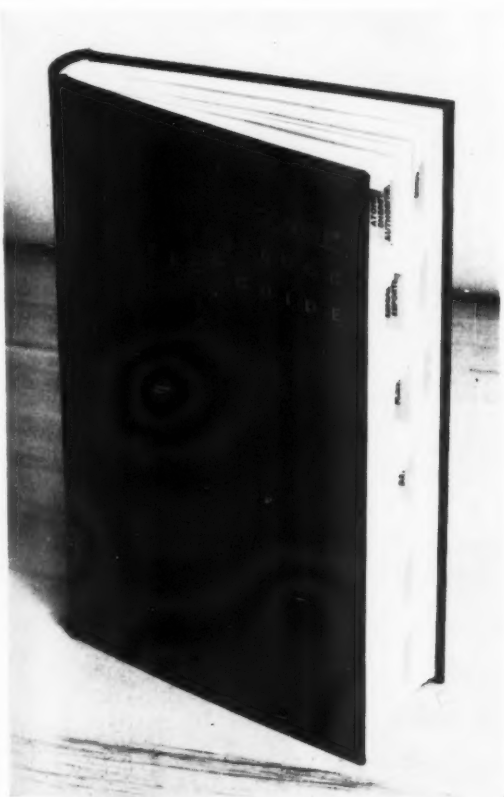

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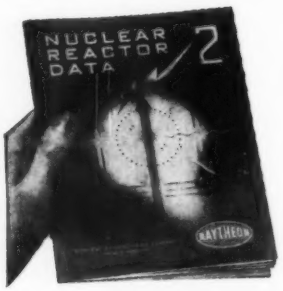

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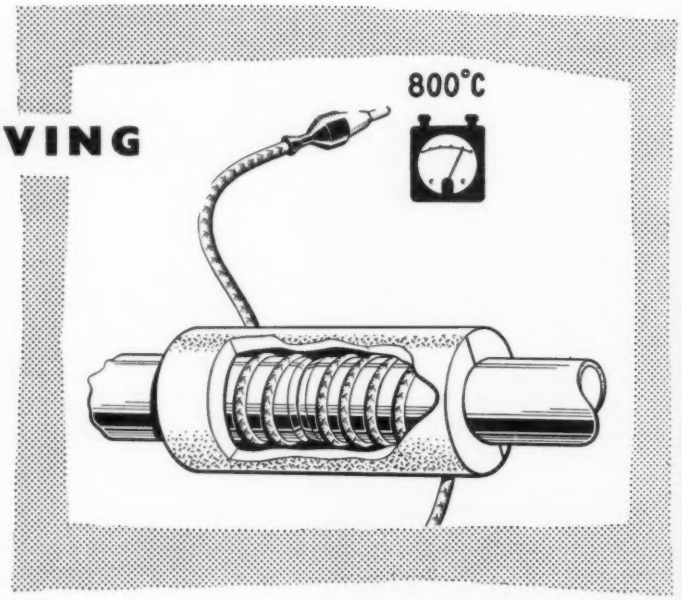

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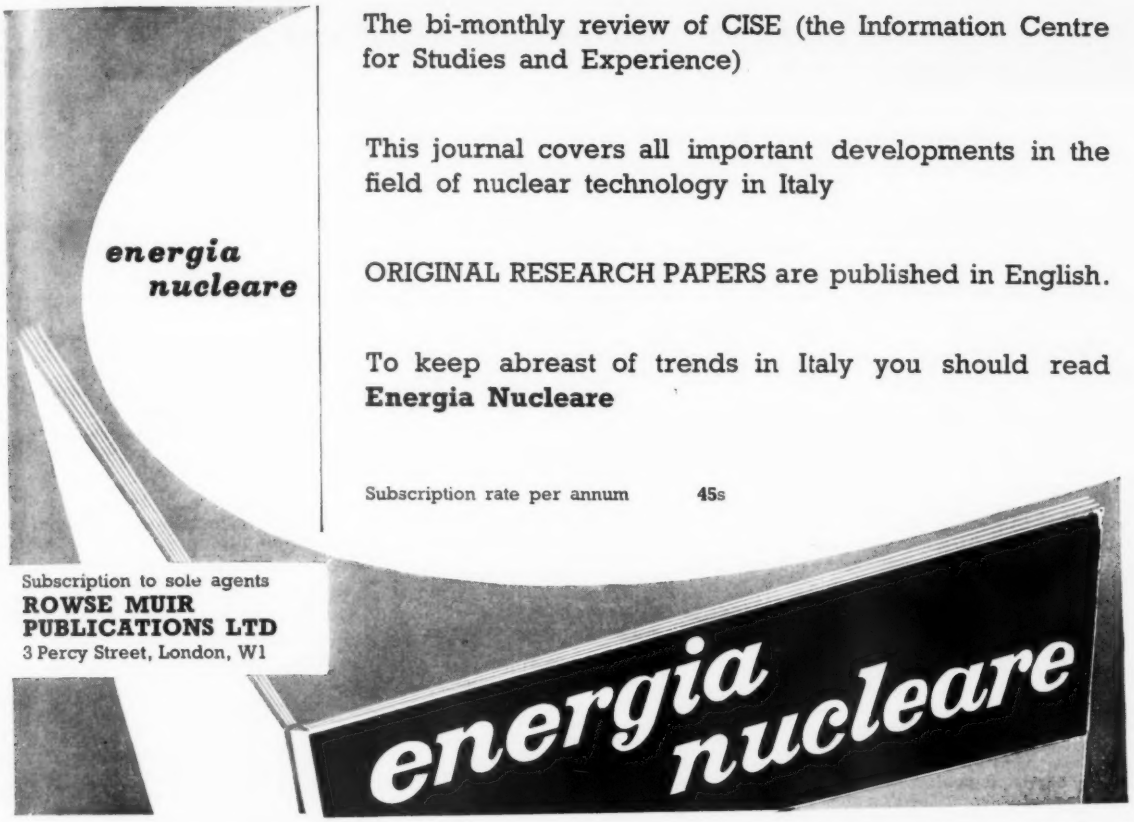

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INDEX TO ADVERTISERS

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AEI Lamps & Lighting Co Ltd	November
AEI–John Thompson Nuclear Energy Co Ltd	February
Aerox Ltd	42
Air Control Installations Ltd	June
Allen, P. W. & Co	March
Amal Ltd	March
Appleby & Ireland Ltd	December
Atomwirtschaft	50
Automatic Telephone & Electric Co Ltd	November
Babcock & Wilcox Ltd	November
Bailey, N. G. & Co Ltd	27
Baldwin Instrument Co Ltd	January
Balfour Beatty & Co Ltd	40
Berk, F. W. & Co Ltd, Schori Division	January
Blakeborough, J. & Sons, Ltd	October
BMB (Sales) Ltd	41
Board of Trade	February
British Acheson Electrodes Ltd	October
British Ermeto Corp. Ltd	43
British Oxygen Gases Ltd	March
British Thomson-Houston Co Ltd, The	39
Bryce Electrical Construction Co Ltd	March
Butterfield, W. P. Ltd	March
Cape Asbestos Co Ltd, The	October
Carbon Dioxide Company, The	March
Carter, B. F. & Co Ltd	February
Cawkell, A. E.	December
Central Electricity Authority	38
Chichester Rubber Co Ltd, The	21
Cinema-Television Ltd	October
Cockburns Ltd	March
Cooling Towers Ltd	July
Cossor Instruments Ltd	January
Costain–John Brown Ltd	May
Crossley Bros. Ltd	February
Darlington Insulation Co Ltd	March
Davenport Engineering Co Ltd	28
Davidson & Co Ltd	March
Dewrance & Co Ltd	November
Dexion Ltd	October
Dowty Nucleonics Ltd	20
Dynatron Radio Ltd	March
Edwards High Vacuum Ltd	May
Ekco Electronics Ltd	March
Electric Furnace Co Ltd	52
Electrothermal Engineering Ltd	52
Elliott Bros (London) Ltd	45
Endecotts (Filters) Ltd	48
Energia Nucleare	53
Engis Ltd	May
Erhard, Johannes	8
Ericsson Telephones Ltd	13
Extrudex Ltd	June
Fairey Aviation Co Ltd, The	October
Fielden Electronics Ltd	January
Firkins, G. & A. Ltd	March
Fisher & Ludlow Ltd	4
Fleming Radio (Developments) Ltd	March
Fulmer Research Ltd	26
Gardner Radio	44
Gardner, Henry & Co Ltd	45
General Electric Co Ltd	19
General Radiological Ltd	53
Gordon, James & Co Ltd	February
Grazebrook, M. & W. Ltd	45
Hanovia	23
Ham, Baker & Co Ltd	December
Harvey, G. A. & Co (London) Ltd	February
Haworth, F. (A.R.C.) Ltd	46
Hayward Tyler & Co Ltd	January
Head, Wrightson & Co Ltd	February
Heather Filters Ltd	March
Her Majesty's Stationery Office	May
Hilger & Watts Ltd	49
Hobson, H. M. Ltd	October
Honeywell-Brown Ltd	3
Hopkinsons Ltd	November
Howden, James & Co Ltd	Inside Back Cover
Humphreys & Glasgow Ltd	25
Imperial Chemical Industries Ltd	March
Industrial Exhibitions Ltd	32
Isotope Developments Ltd	16
IV Pressure Controllers Ltd	6
Johnstone, Archibald Ltd	March
KDG Instruments Ltd	December
Keith Blackman Ltd	5
Kent, Ltd, George	November
Klaxon Electrical Engineers Ltd	December
Kodak Ltd	18
Labgear (Cambridge) Ltd	2
Laboratory Apparatus & Glassblowing Co	46
Laing & Son, Ltd, John	124
Lake & Elliot Ltd	13
Lead Development Association	September
Leybold Vacuum Sales Ltd	June
Londex Ltd	November
Lyons Ltd, Claude	March
Magnetic Valve Co Ltd	32
Mallinson, William & Sons Ltd	47
Marston Excelsior Ltd	February
Martonair Ltd	49
McGraw-Hill Publishing Co Ltd	February
Measuring Instruments (Pullin) Ltd	December
Metropolitan-Vickers Electrical Co Ltd	33
Micanite & Insulator Co Ltd	December
Miller, P. & L. Ltd	June
Mills Scaffold Co Ltd	Inside Front Cover
Mitchell Engineering Ltd	Front Cover
Moler Products Ltd	48
Mollart Engineering Ltd	January
Morgan Crucible Co Ltd, The	43
Mullard Ltd	November
Mullard X-Ray Division	12
Munro & Miller Ltd	46
Murex Welding Processes Ltd	29
Nash & Thompson Ltd	43
New Metals & Chemicals Ltd	December
Nuclear Enterprises (GB) Ltd	50
Nuclear Graphite Ltd	37
Nuclear Power Plant Co Ltd, The	February
Nuclear Research Applications	May
Ozonair Engineering Co Ltd	October
Panax Equipment Ltd	March
Pascall Engineering Co Ltd, The	50
Philips Electrical Ltd.	1
Physical Society Ltd	March
Plessey Co Ltd	October
Powell Duffryn Carbon Products Ltd	14
Pye Ltd (Industrial TV Division)	17
Pyrene Co Ltd, The	126
Racal Engineering Ltd	March
Rawlplug Ltd	24
Raytheon Manufacturing Co	52
RFD Co Ltd (Protective Safety Division)	June
Rotameter Manufacturing Co Ltd	August
Sangamo Weston Ltd	44
Savage & Parsons Ltd	Back Cover
Shandon Scientific Co Ltd	February
Shaw-Petrie Ltd	10
Shell Chemical Co Ltd	February
Shell Mex & BP Ltd	November
Silica Gel Ltd	42
Simplifix Couplings Ltd	March
Smith, J. & Sons (Clerkenwell) Ltd	47
Southern Instruments Ltd	March
Stephen, R. A. & Co Ltd	June
Stillite Products Ltd	December
Sunvic Controls Ltd	36
Talbot Stead Tube Co Ltd	9
Taylor Woodrow Ltd	November
Teddington Aircraft Controls Ltd	15
Temperature Ltd	July
Thermo-Plastics Ltd	June
Thompson, John Ltd	34, 35
Timeg Ltd	51
Titanium Metal & Alloys Ltd	48
Tube Investments Ltd	May
20th Century Electronics Ltd	August
Unit Superheater & Pipe Co Ltd	February
United Nations Information Service	August
Veedip Ltd	December
Vokes Ltd	16
Weir, G. & J. Ltd	7
Western Detail Manufacturing Ltd	22
Wharton Crane & Hoist Co Ltd	11
Whessoe Ltd	January
Wilkinson Rubber Linatex Ltd	December
Wright Anderson & Co Ltd	November

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S

mber 5
mber
mber 18
2
46
124
13
mber June
mber March
32
47
ruary 49
ruary
mber 33
mber June
Cover
Cover 48
nuary 43
ember 12
46
29
43
ember 50
37
ruary May
tober
March 50
1
March
tober 14
17
126
March 24
52
June
August 44
Cover
ruary 10
ruary
ember 42
March 47
March June
ember 36
9
ember 15
July
June 34, 35
51
48
May
August
bruary
August
ember 16
7
22
11
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ember

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5
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18

2
46
124
13
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47
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49
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33
ber
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48
uary
43
nber
12
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29

43
nber
50
37
uary
May
ober
arch
50
1
arch
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14
17
126

arch
24
52
June
gust
44
over
uary
10
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nber
42
arch
47
arch
June
nber
36

9
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16

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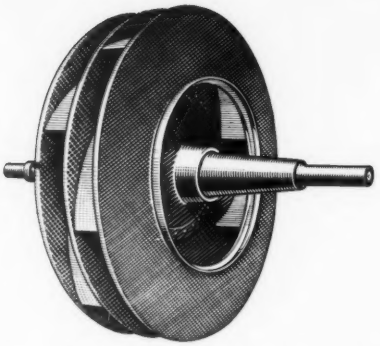

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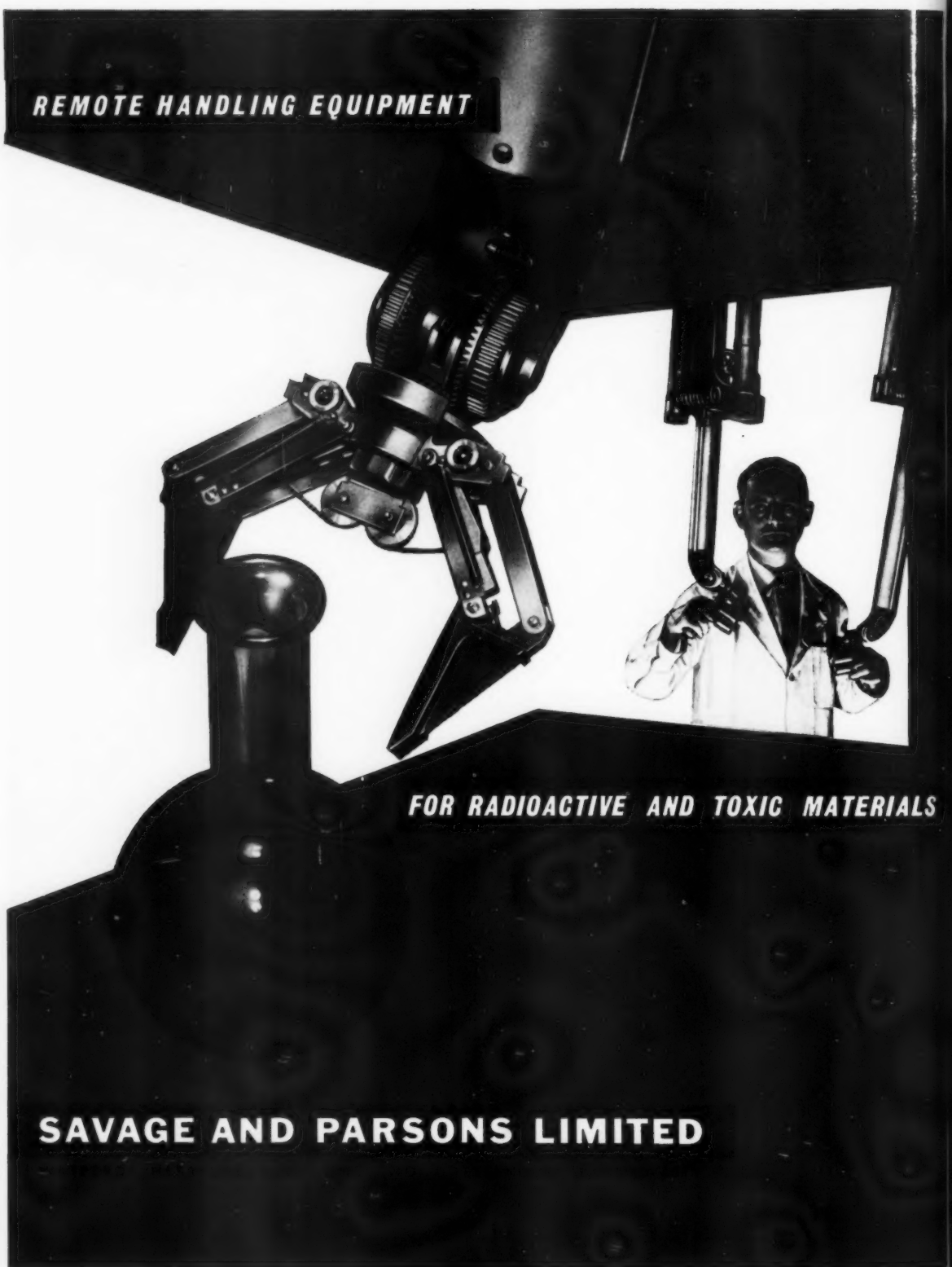

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